# DCE-12

3 February 1997

Data Report

# Dielectric Properties of Soils

## Fort A. P. Hill, VA -- 2nd Sample Set


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## Clifton, Peggy

**From:** George, Vivian Ms PM-MCD [vivian.george@nvl.army.mil]
**Sent:** Friday, April 27, 2001 9:27 AM
**To:** 'Clifton, Peggy'
**Subject:** RE: Distribution on DARPA/Walcoff Documents & Data

All are approved for public distribution A, unlimited.

-----Original Message-----
From: Clifton, Peggy [mailto:pclifton@dtic.mil]
Sent: Wednesday, April 11, 2001 9:50 AM
To: 'Vivian George'
Subject: Distribution on DARPA/Walcoff Documents & Data

Vivian,

I am putting in the background clutter data documents and discs; some are marked "Approved for public release, distribution is unlimited," but others have no markings for distribution. Are they all unlimited distribution? If, not we will have to figure out what the distribution levels are for the unmarked documents. TIA,

Peg Clifton

Margaret Clifton
Nonprint Program Manager
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"Civilization advances by extending the number
of important operations which we can perform without thinking about them."
-Alfred North Whitehead

## Introduction

This report contains dielectric property measurement results for soils. The original data were collected in the form of the real and imaginary parts of the complex dielectric constant versus frequency utilizing a Hewlett-Packard 8510C Vector Network Analyzer System with an S-Parameter Test Set and a coaxial sample holder. Software developed at the U.S. Army Engineer Waterways Experiment Station was used to convert S-parameter measurements at selected frequencies into a complex dielectric constant. The soils were assumed to be nonmagnetic. Other useful electromagnetic properties were calculated from the dielectric constant and frequency, including an equivalent electrical conductivity, the loss tangent, power attenuation, and a normalized phase velocity. The section entitled, "Fundamental Relationships," contains the formulae used to calculate these properties. Additional physical parameters of the soil samples that are included in the report include their dry density, volumetric moisture content, and temperature.

Measurement results and calculated parameters are listed at four selected frequencies and displayed as a function of volumetric moisture content. The intent of presenting data in this way is to demonstrate the experimental observation that the real part of the dielectric constant, as well as the normalized phase velocity are strong functions of volumetric moisture and reasonably independent of soil texture. Other parameters are clearly dependent on soil texture, and, given enough data from several different types of soils, their graphs versus moisture content would show a great deal of scatter. The four frequencies chosen for data presentation span the range of frequencies normally associated with ground penetrating radars.

For additional details on how the data were collected, please contact the first author at the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, (voice: 601-634-2855, FAX: 601-634-2732, e-mail: curtisj@ex1.wes.army.mil).

## Source of Soil Samples

The samples used for these measurements were collected in the last week of August, 1996, by Messrs. Chuck Hahn, David Leese, and Joe Wooley, all members of the site investigation team from WES. Bag samples of soil were taken from five different locations on each test site at Fort A.P. Hill. At each of these five locations a near-surface sample was acquired along with a sample at a depth of about 0.5 meters and another at a depth of about 1.0 meter.

The two test sites at Fort A.P. Hill were located at Firing Point 20 and Firing Point 22. Each individual soil sample has been given unique identifiers making use of the site name, the easting coordinate, in meters (relative to the southwest corner of the test site), where the sample was collected, and the depth from which it was taken. The character "1" was used for samples taken from a depth of one meter; a "2" was assigned to those collected at one-half of a meter; and an "s" identifies surface samples. One additional character was added to the sample identifier to indicate whether the soil used came straight from the sample bag in an "as is" condition (the letter "b"), or had been air dried while still in the sample holder (the letter "d"), or, finally, had been wetted with distilled deionized water while still in the sample holder (the letter "w"). Using these guidelines, the sample identifier , 20123_2d, refers to a sample collected from the Firing Point 20 test site at a location 123 meters east and 97 meters north of the southwest corner, at a depth of 0.5 meters, and which had been air-dried prior to measurement of its electrical properties.

## Experimental Procedures

The experimental procedure used to collect electrical property data at WES normally consists of the following steps. First of all, soil is taken from the source container and packed into a brass coaxial sample holder using small spoons and other utensils. The holders used in these measurements have a square cross section whose dimension is 0.75 cm and are either 5 cm or 10 cm in length, resulting in total sample volumes of about 2.8 $cm^3$ and 5.6 $cm^3$, respectively. The samples are packed as tightly as possible at whatever moisture content they retained in the bags. Hence, there is no control over sample dry density. It is highly unlikely, however, that the densities achieved by this sample preparation technique will ever exceed *in situ* densities.

After enclosing the sample in the holder with a brass cover plate, the holder is placed in a temperature control device and connected to the S-parameter test set. After the sample has reached the desired temperature, data are collected over the selected range of frequencies. Following removal of the sample holder from the temperature control apparatus, the cover plate is removed, and the sample is allowed to air dry (usually for a twenty-four hour period). After the collected of a second set of data at nominally-dry conditions, the sample is wetted to near saturation by the careful addition of distilled, deionized water. After allowing some time for the added moisture to fully penetrate the soil structure (usually about an hour), the electrical properties are once again measured. Therefore, each sample is tested three times, once as is, once after air drying, and once at near-saturation conditions. The addition of water would not work for a sample that contained a large amount of swelling clay minerals, as the sample would expand too far out of the sample holder to allow a measurement to be made.

Sample masses are recorded prior to each measurement. Following the last data collection, the soil is scraped and flushed from the sample holder and dried in an oven to obtain its dry mass, which, by virtue of knowing the sample volume, leads to the sample dry density and the calculation of sample volumetric moisture contents for each measurement. Of course, these data can also be used to calculate the commonly used weight-based moisture content as well.

## Fundamental Relationships

Assuming plane harmonic wave propagation in a lossy, non-magnetic, unbounded medium, the wave amplitude function may be written:

$$e^{i(kx - \omega t)}$$

where

$k$ $= \beta + i\alpha$ $= \omega N/c$

is the complex propagation constant,

$\beta$ is the phase constant,

$\alpha$ is the amplitude attenuation factor,

$\omega$ is the radial frequency,

$N$ is the complex index of refraction,

$c$ is the velocity of light in a vacuum,

$i$ is the symbol designating an imaginary quantity = $\sqrt{-1}$ ,

$x$ is a space coordinate, and

$t$ is time.

Furthermore,

$$N^2 = \epsilon = \epsilon' + \epsilon''$$

where $\epsilon$ is the relative complex dielectric constant, which, along with the electrical conductivity from Ohm's Law, represents the electrical properties of the medium. The interpretation of these properties as used in this study is that the conductivity, $\sigma$ , accounts for current due to free charged particle motion, while the imaginary part of the complex dielectric constant, $\epsilon''$ , accounts for displacement current losses (those due to the electric polarization of the medium). When both conduction and displacement currents are considered, one finds two terms in Ampere's law for current flow that represent losses (or a shift in phase), one containing the electrical conductivity and one containing the imaginary part of the dielectric constant. While these two terms account

for different loss mechanisms, most researchers use only one term or the other to identify losses, with many users preferring to deal with the concept of electrical conductivity. In MKS units, the relationship between the two quantities is taken to be

$$\sigma = \epsilon'' \epsilon_0 \omega$$

where the units of conductivity are mhos/meter (or siemens/meter) and $\epsilon_0$ is the permittivity of free space ($8.85 \times 10^{-12}$ farads/meter).

Squaring the expression for the complex propagation constant, substituting the expression for the square of the complex index of refraction, and equating real and imaginary components, one obtains two algebraic equations that relate the amplitude attenuation factor and phase constant to the complex dielectric constant:

$$\beta^2 - \alpha^2 = \frac{\omega^2}{c^2}\epsilon'$$

and

$$\alpha\beta = \frac{\omega^2 \epsilon''}{2c^2}$$

Solving these equations for the amplitude attenuation factor and for the phase constant results in the following expressions:

$$\alpha = \frac{\omega}{c}\left( \frac{\epsilon'}{2}\left( \sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} - 1 \right) \right)^{1/2}$$

and

$$\beta = \frac{\omega}{c}\left( \frac{\epsilon'}{2}\left( \sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} + 1 \right) \right)^{1/2}$$

The $\epsilon''/\epsilon'$ ratio is also referred to as the loss tangent. Some researchers prefer to work with the electrical conductivity in place of the dielectric loss term.

Plane waves of constant phase will propagate with a velocity

$$v = \frac{\omega}{\beta} = c\left( \frac{\epsilon'}{2}\left( \sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} + 1 \right) \right)^{-1/2}$$

This phase velocity is not necessarily the speed with which the energy of the wave propagates through the

medium. The latter is refered to as the group velocity and can be calculated as the rate of change of radial frequency with respect to the phase constant. However, as long as the phase velocity is relatively constant over the range of frequencies of interest, then there is little difference between phase velocity and group velocity.

The power intensity of the plane electromagnetic wave decreases exponentially with depth of penetration by the factor, $e^{-2\alpha x}$, or, in one unit of distance traveled, a decrease of $e^{-2\alpha}$. Power attenuation expressed in decibels per meter can then be written as:

$$PL = -8.6859 \frac{\omega}{c} \left( \frac{\epsilon'}{2} \left( \sqrt{1 + \left( \frac{\epsilon''}{\epsilon'} \right)^2} - 1 \right) \right)^{1/2}$$

## Theoretical Loss Tangent Effects

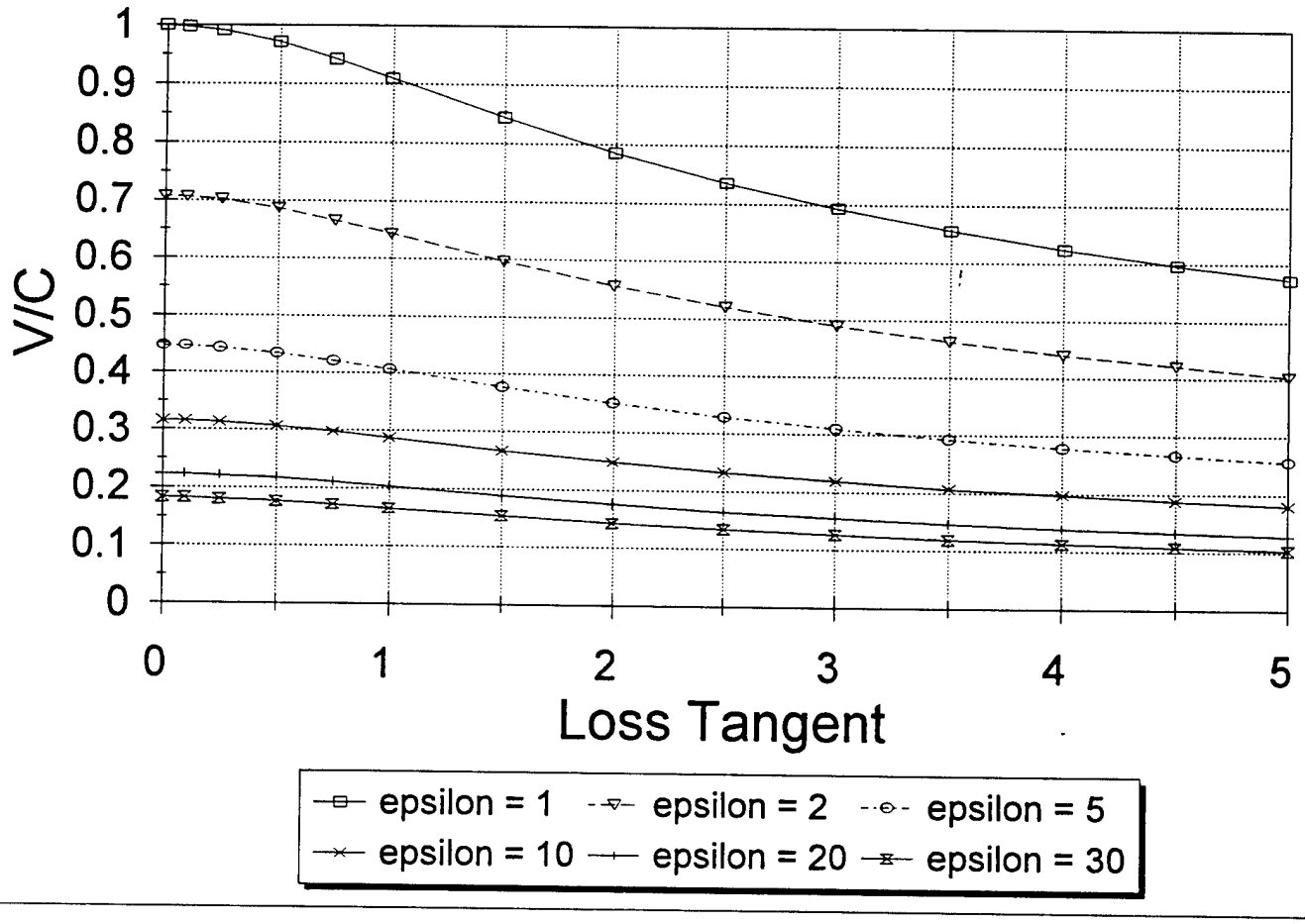
The most straightforward design of a ground-penetrating radar data collection effort and subsequent analysis of those data would require estimates of the speed with which a radar signal will propagate through the terrain and the rate at which the power level of the signal will be attenuated. The former provides the locations of subsurface anomalies, while the latter controls the depth to which meaningful data can be collected.

Usually, phase velocity is taken to be a good approximation of electromagnetic wave speed. Furthermore, many designers and analysts choose to assume that the material through which the wave is propagating is relatively lossless. The first figure that follows is a plot of normalized phase velocity ($v/c$) for selected values of the real part of the complex dielectric constant (often referred to as the permittivity of the material) against values of the loss tangent. The permittivity values easily span the range of values found in most soils. The figure clearly demonstrates that as long as the loss tangent is relatively small (say, less than 0.5), the lossless material assumption is a good one. However, a loss tangent of 1.0, which is not uncommon, will result in about a ten percent error in phase velocity compared to the lossless assumption.

As for signal power attenuation, obviously the lossless material assumption is meaningless. One can see from the second plot that follows that the rate at which the power level of an electromagnetic wave decreases when traveling through the soil is very sensitive to the value of the loss tangent and to the frequency at which the signal is being propagated.

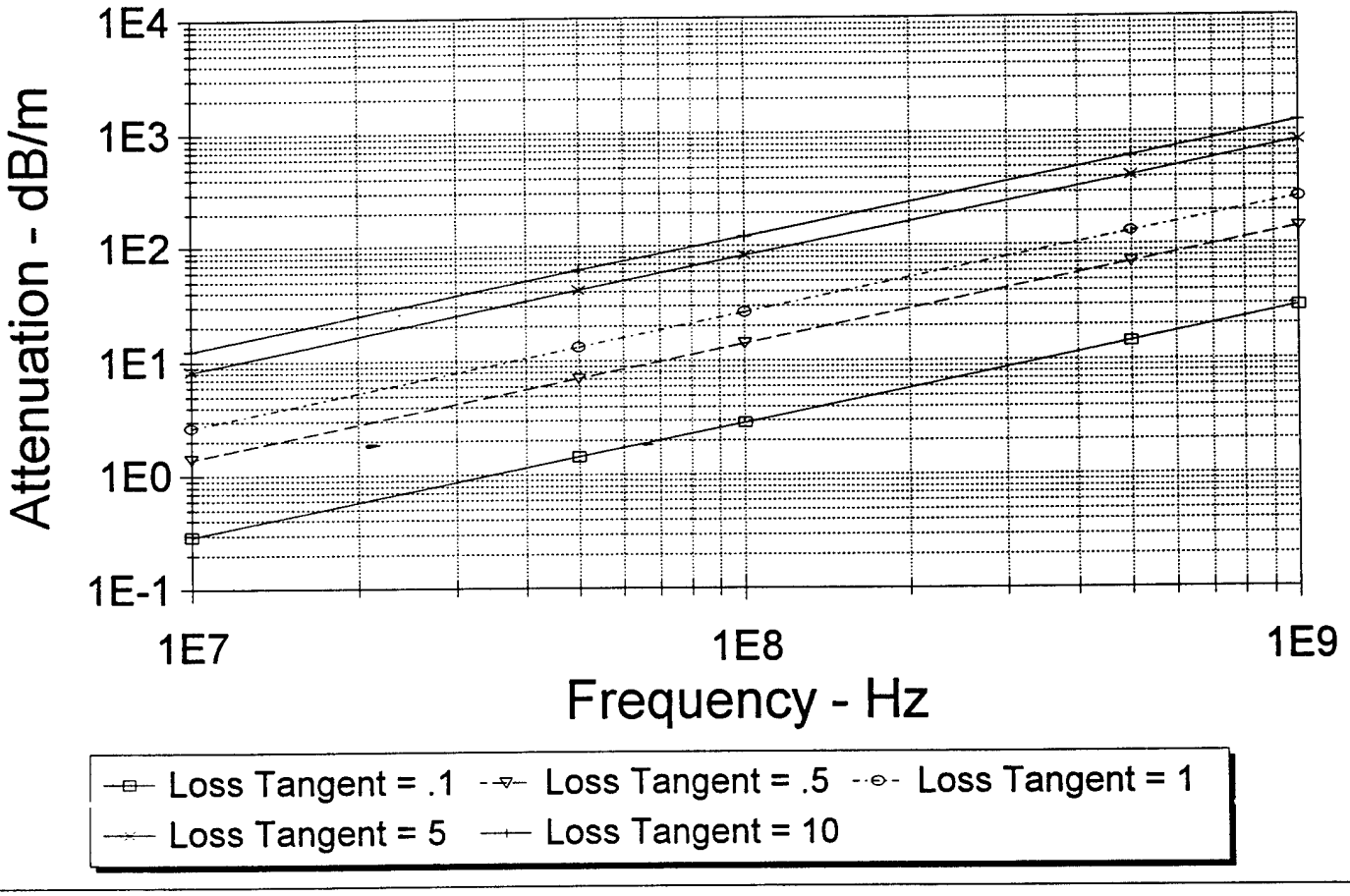
# Loss Tangent Effects

## Normalized Phase Velocity



# Loss Tangent Effects

Attenuation (Permittivity = 10)



## Representative Data

The following pages contain a sample of the electrical property data associated with these Fort A.P. Hill soil samples. Although laboratory data are collected as a function of frequency for a constant value of volumetric moisture, it has been found that one particularly useful format for displaying these data is to plot results (both measured and calculated) versus moisture content at selected frequencies. The frequencies chosen for this report are 50, 100, 200, and 895 MHz, and were chosen to be representative of the normal operating frequencies of ground penetrating radar systems.

At each frequency, the data are presented in the following way. First of all, one will find a table of measured and calculated parameters, the first page being for samples taken from Firing Point 20, and the second page being for Firing Point 22 samples. The first column of each page provides the location and depth code, while the second column lists the volumetric moisture content (in percent) of that particular sample. The third column contains the dry density (in grams per cubic centimeters) of the sample that was tested. The last six columns list the real and imaginary components of the measured relative complex dielectric constant, the equivalent conductivity (in mhos per meter), the loss tangent, the power attenuation factor in decibels per meter, and the normalized phase velocity.

The table is followed by several plots of parameters versus volumetric moisture. The first six plots represent a composite of all sample depths and both test sites. Experience from previous data collection efforts with many different types of soils has shown that the permittivity and the normalized phase velocity are very strong functions of volumetric moisture and virtually independent of soil type. These data confirm those previous observations. The first six plots clearly establish that there is no fundamental difference in electrical property values for the two test sites.

The next question to be answered is whether or not sample depth makes a difference in electrical properties. This question is addressed by plotting the six parameters versus moisture content while distinguishing sample depth. Six plots appear for the Firing Point 20, and six plots are shown for the Firing Point 22 soils. Once again, the overwhelming conclusion is that there is no difference in electrical properties as a result of sample depth.

Fort A.P. Hill_2
Properties at 50 Mhz

Fort AP Hill_2 Soil Properties at 50 MHz

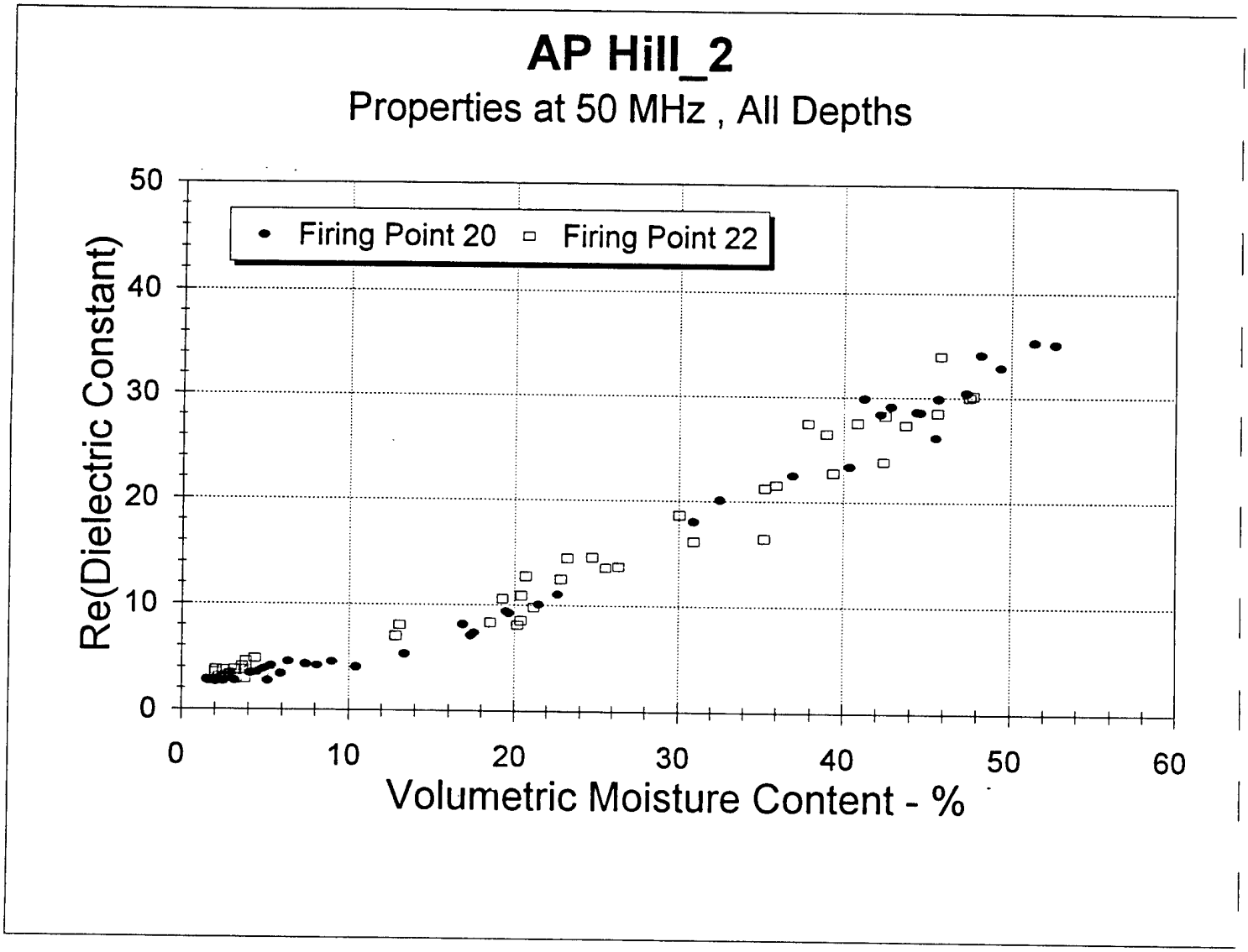
Firing Point 20

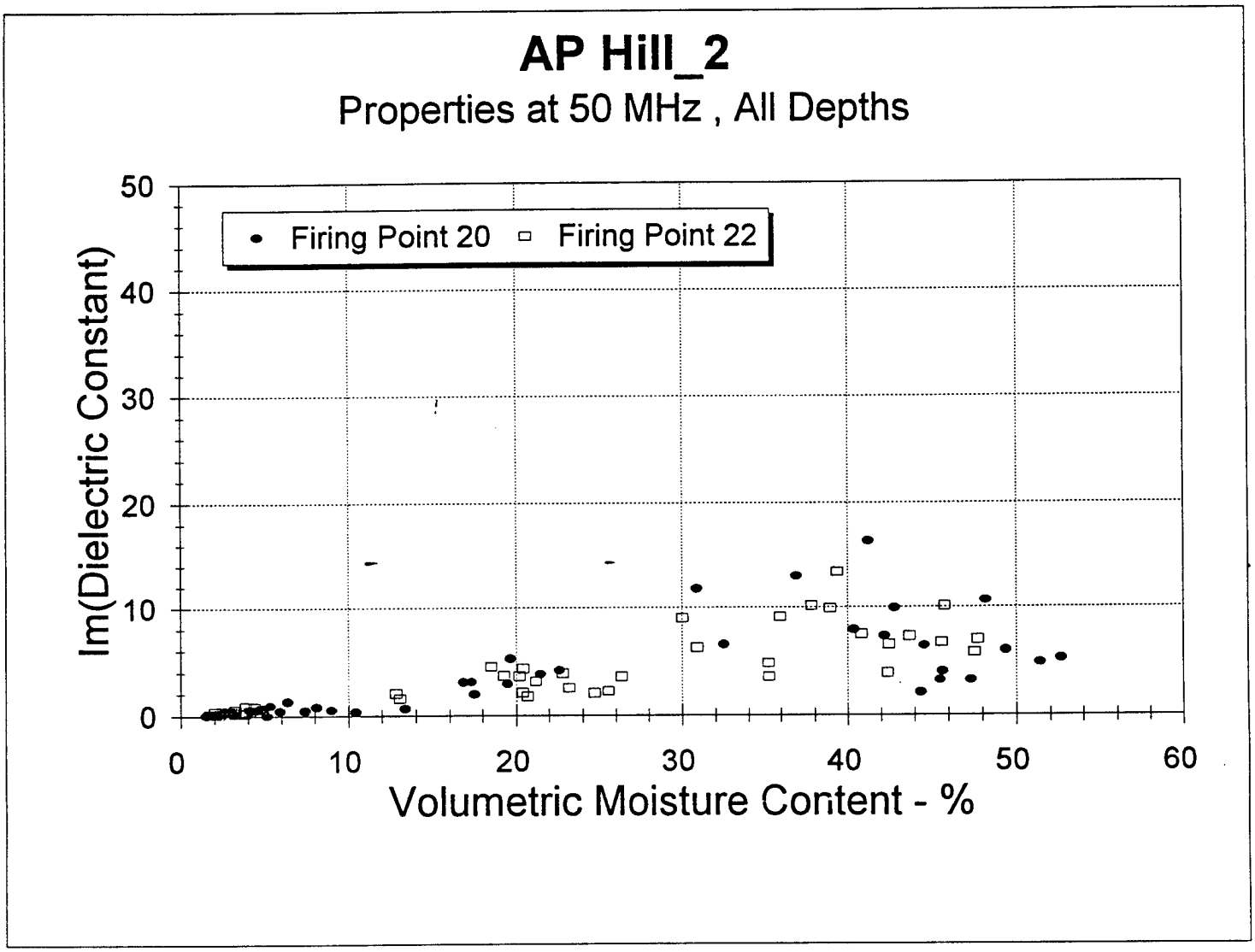
| File Name | Vol Moist | Dry Dens g/cc | Re(eps) | Im(eps) | Cond mho/m | Loss Tan | Attn dB/m | Norm Vel |
|---|---|---|---|---|---|---|---|---|
| 200_1b | 2.57 | 1.40 | 3.22 | 0.33 | 0.001 | 0.10 | 0.84 | 0.56 |
| 200_1d | 2.65 | 1.40 | 3.25 | 0.39 | 0.001 | 0.12 | 0.98 | 0.55 |
| 200_1w | 49.42 | 1.40 | 32.93 | 6.00 | 0.017 | 0.18 | 4.74 | 0.17 |
| 200_2b | 5.97 | 1.21 | 3.41 | 0.47 | 0.001 | 0.14 | 1.16 | 0.54 |
| 200_2d | 2.52 | 1.21 | 2.69 | 0.23 | 0.001 | 0.08 | 0.62 | 0.61 |
| 200_2w | 51.44 | 1.21 | 35.35 | 4.84 | 0.014 | 0.14 | 3.69 | 0.17 |
| 200_sb | 9.01 | 1.39 | 4.54 | 0.55 | 0.002 | 0.12 | 1.17 | 0.47 |
| 200_sd | 2.27 | 1.39 | 2.92 | 0.18 | 0.001 | 0.06 | 0.47 | 0.58 |
| 200_sw | 47.36 | 1.39 | 30.48 | 3.23 | 0.009 | 0.11 | 2.66 | 0.18 |
| 20122_1b | 30.94 | 1.53 | 18.03 | 11.83 | 0.033 | 0.66 | 12.09 | 0.22 |
| 20122_1d | 6.41 | 1.53 | 4.54 | 1.35 | 0.004 | 0.30 | 2.85 | 0.46 |
| 20122_1w | 41.25 | 1.53 | 29.91 | 16.37 | 0.046 | 0.55 | 13.16 | 0.18 |
| 20122_2b | 16.89 | 1.37 | 8.20 | 3.10 | 0.009 | 0.38 | 4.84 | 0.34 |
| 20122_2d | 2.98 | 1.37 | 3.47 | 0.47 | 0.001 | 0.14 | 1.15 | 0.54 |
| 20122_2w | 48.22 | 1.37 | 34.13 | 10.68 | 0.030 | 0.31 | 8.22 | 0.17 |
| 20122_sb | 17.37 | 1.47 | 7.14 | 3.12 | 0.009 | 0.44 | 5.19 | 0.37 |
| 20122_sd | 3.19 | 1.47 | 2.73 | 0.14 | 0.000 | 0.05 | 0.37 | 0.61 |
| 20122_sw | 40.39 | 1.47 | 23.34 | 7.93 | 0.022 | 0.34 | 7.36 | 0.20 |
| 20123_1b | 8.11 | 1.33 | 4.21 | 0.81 | 0.002 | 0.19 | 1.78 | 0.49 |
| 20123_1d | 1.61 | 1.33 | 2.74 | 0.18 | 0.001 | 0.06 | 0.49 | 0.60 |
| 20123_1w | 52.69 | 1.33 | 35.15 | 5.25 | 0.015 | 0.15 | 4.02 | 0.17 |
| 20123_2b | 21.49 | 1.66 | 10.13 | 3.84 | 0.011 | 0.38 | 5.40 | 0.31 |
| 20123_2d | 4.55 | 1.66 | 3.52 | 0.56 | 0.002 | 0.16 | 1.36 | 0.53 |
| 20123_2w | 32.55 | 1.66 | 20.12 | 6.56 | 0.018 | 0.33 | 6.56 | 0.22 |
| 20123_sb | 19.71 | 1.54 | 9.26 | 5.28 | 0.015 | 0.57 | 7.60 | 0.32 |
| 20123_sd | 1.95 | 1.54 | 2.87 | 0.10 | 0.000 | 0.03 | 0.26 | 0.59 |
| 20123_sw | 36.96 | 1.54 | 22.48 | 12.99 | 0.036 | 0.58 | 12.01 | 0.20 |
| 2027_1b | 7.44 | 1.53 | 4.33 | 0.47 | 0.001 | 0.11 | 1.03 | 0.48 |
| 2027_1d | 1.54 | 1.53 | 2.78 | 0.05 | 0.000 | 0.02 | 0.15 | 0.60 |
| 2027_1w | 44.38 | 1.53 | 28.61 | 2.08 | 0.006 | 0.07 | 1.77 | 0.19 |
| 2027_2b | 22.63 | 1.53 | 11.08 | 4.21 | 0.012 | 0.38 | 5.65 | 0.30 |
| 2027_2d | 5.34 | 1.53 | 4.11 | 0.92 | 0.003 | 0.22 | 2.06 | 0.49 |
| 2027_2w | 42.86 | 1.53 | 29.13 | 9.91 | 0.028 | 0.34 | 8.24 | 0.18 |
| 2027_sb | 10.49 | 1.44 | 4.04 | 0.38 | 0.001 | 0.09 | 0.86 | 0.50 |
| 2027_sd | 5.16 | 1.44 | 2.73 | 0.07 | 0.000 | 0.03 | 0.19 | 0.61 |
| 2027_sw | 45.55 | 1.44 | 26.16 | 3.23 | 0.009 | 0.12 | 2.87 | 0.20 |
| 2065_1b | 17.55 | 1.47 | 7.40 | 1.99 | 0.006 | 0.27 | 3.30 | 0.36 |
| 2065_1d | 4.15 | 1.47 | 3.43 | 0.52 | 0.001 | 0.15 | 1.26 | 0.54 |
| 2065_1w | 44.58 | 1.47 | 28.58 | 6.43 | 0.018 | 0.22 | 5.44 | 0.19 |
| 2065_2b | 19.52 | 1.48 | 9.44 | 2.97 | 0.008 | 0.31 | 4.34 | 0.32 |
| 2065_2d | 4.91 | 1.48 | 3.84 | 0.68 | 0.002 | 0.18 | 1.58 | 0.51 |
| 2065_2w | 42.22 | 1.48 | 28.39 | 7.30 | 0.020 | 0.26 | 6.18 | 0.19 |
| 2065_sb | 13.39 | 1.37 | 5.32 | 0.69 | 0.002 | 0.13 | 1.36 | 0.43 |
| 2065_sd | 2.09 | 1.37 | 2.62 | 0.14 | 0.000 | 0.05 | 0.40 | 0.62 |
| 2065_sw | 45.70 | 1.37 | 29.89 | 4.02 | 0.011 | 0.13 | 3.34 | 0.18 |

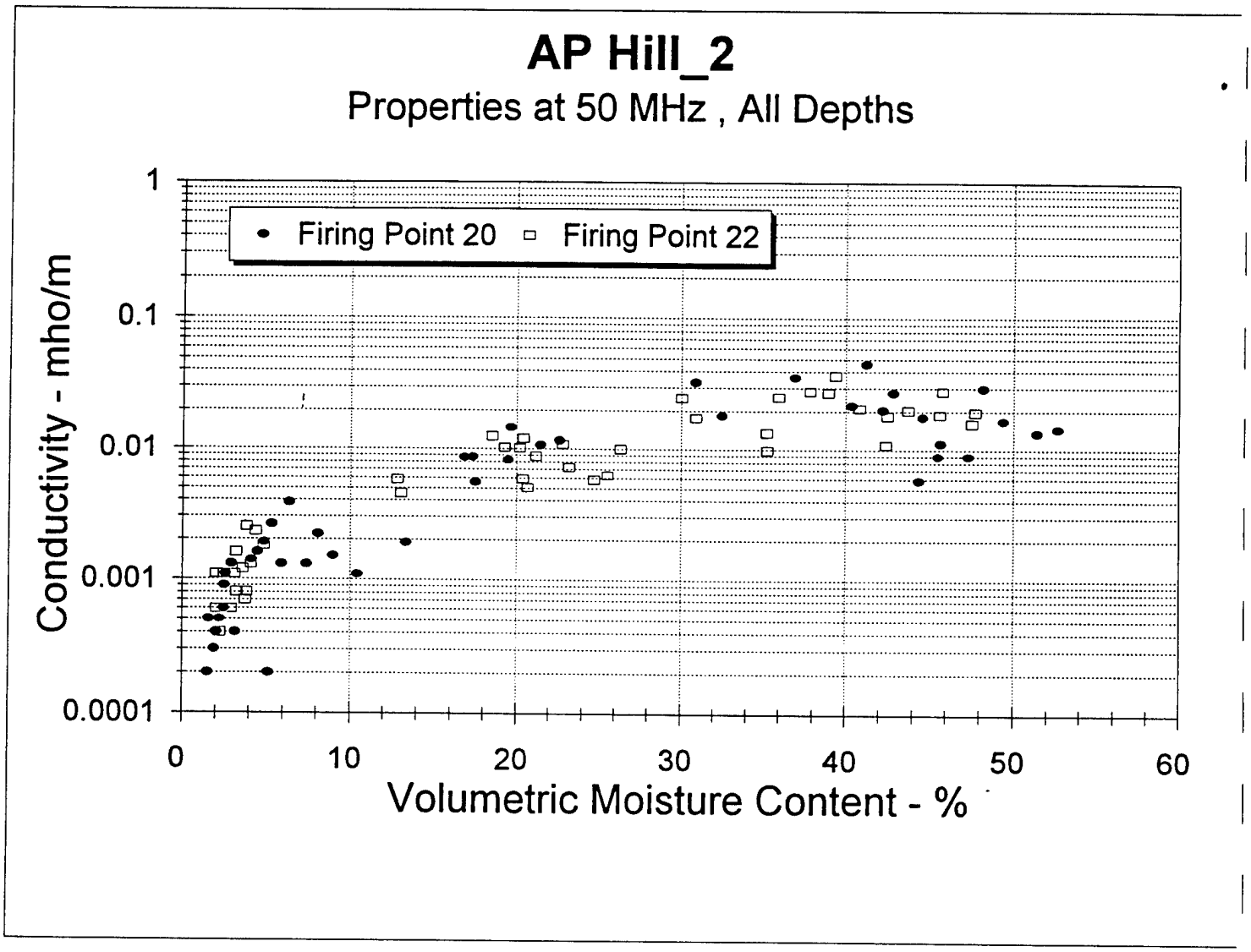
Fort AP Hill_2 Soil Properties at 50 MHz

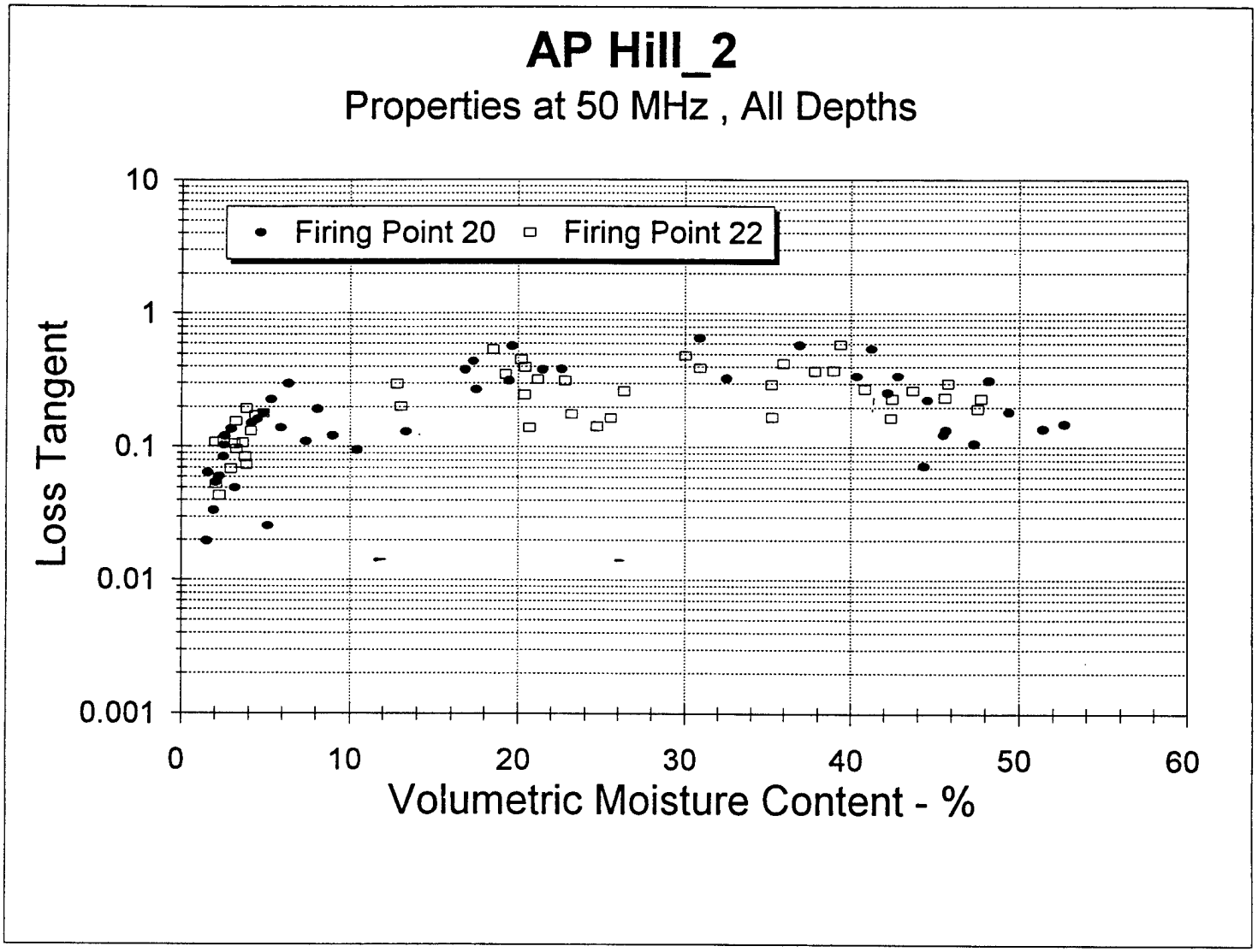
Firing Point 22

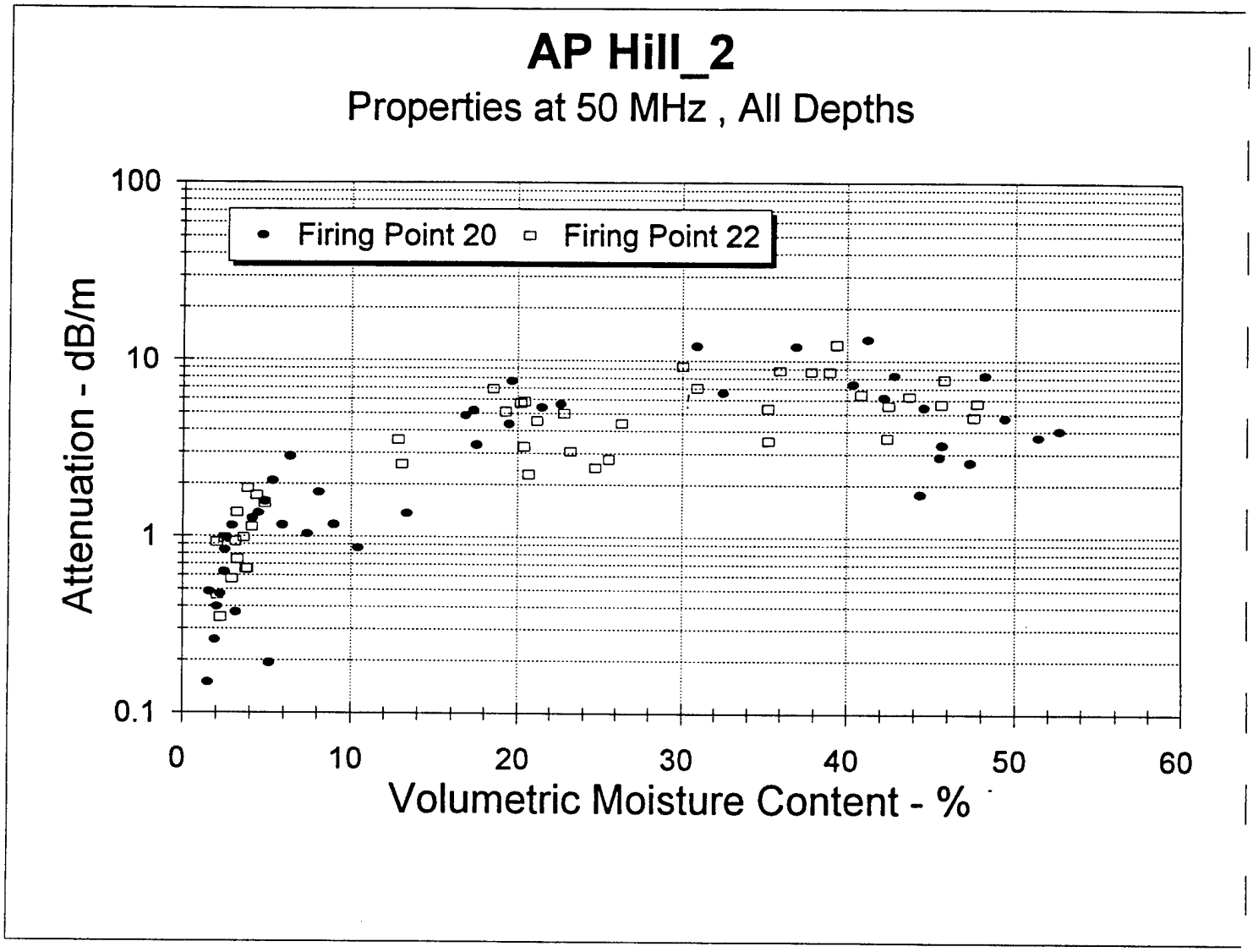
| File Name | Vol Moist | Dry Dens g/cc | Re(eps) | Im(eps) | Cond mho/m | Loss Tan | Attn dB/m | Norm Vel |
|---|---|---|---|---|---|---|---|---|
| 22122_1b | 19.30 | 1.53 | 10.63 | 3.72 | 0.010 | 0.35 | 5.11 | 0.30 |
| 22122_1d | 3.88 | 1.53 | 4.59 | 0.88 | 0.003 | 0.19 | 1.87 | 0.46 |
| 22122_1w | 45.79 | 1.53 | 34.02 | 10.15 | 0.028 | 0.30 | 7.83 | 0.17 |
| 22122_2b | 20.45 | 1.83 | 10.95 | 4.34 | 0.012 | 0.40 | 5.86 | 0.30 |
| 22122_2d | 2.94 | 1.83 | 3.37 | 0.23 | 0.001 | 0.07 | 0.57 | 0.54 |
| 22122_2w | 35.24 | 1.83 | 16.46 | 4.84 | 0.014 | 0.29 | 5.37 | 0.24 |
| 22122_sb | 13.05 | 1.69 | 8.08 | 1.62 | 0.005 | 0.20 | 2.58 | 0.35 |
| 22122_sd | 2.04 | 1.69 | 3.54 | 0.39 | 0.001 | 0.11 | 0.93 | 0.53 |
| 22122_sw | 35.25 | 1.69 | 21.26 | 3.57 | 0.010 | 0.17 | 3.51 | 0.22 |
| 22123_1b | 21.20 | 1.53 | 9.83 | 3.17 | 0.009 | 0.32 | 4.54 | 0.32 |
| 22123_1d | 4.87 | 1.53 | 3.67 | 0.65 | 0.002 | 0.18 | 1.54 | 0.52 |
| 22123_1w | 43.69 | 1.53 | 27.37 | 7.30 | 0.020 | 0.27 | 6.29 | 0.19 |
| 22123_2b | 12.82 | 1.51 | 7.06 | 2.08 | 0.006 | 0.30 | 3.53 | 0.37 |
| 22123_2d | 3.22 | 1.51 | 3.73 | 0.58 | 0.002 | 0.16 | 1.36 | 0.52 |
| 22123_2w | 45.59 | 1.51 | 28.53 | 6.72 | 0.019 | 0.24 | 5.68 | 0.19 |
| 22123_sb | 18.55 | 1.55 | 8.38 | 4.52 | 0.013 | 0.54 | 6.87 | 0.33 |
| 22123_sd | 3.80 | 1.55 | 2.98 | 0.25 | 0.001 | 0.08 | 0.66 | 0.58 |
| 22123_sw | 39.36 | 1.55 | 22.72 | 13.42 | 0.037 | 0.59 | 12.31 | 0.20 |
| 2227_1b | 26.33 | 1.51 | 13.70 | 3.61 | 0.010 | 0.26 | 4.40 | 0.27 |
| 2227_1d | 3.15 | 1.51 | 3.80 | 0.40 | 0.001 | 0.11 | 0.93 | 0.51 |
| 2227_1w | 42.47 | 1.51 | 28.28 | 6.54 | 0.018 | 0.23 | 5.56 | 0.19 |
| 2227_2b | 37.85 | 1.66 | 27.50 | 10.19 | 0.028 | 0.37 | 8.70 | 0.19 |
| 2227_2d | 4.37 | 1.66 | 4.83 | 0.83 | 0.002 | 0.17 | 1.71 | 0.45 |
| 2227_2w | 38.96 | 1.66 | 26.50 | 9.92 | 0.028 | 0.37 | 8.62 | 0.19 |
| 2227_sb | 47.54 | 1.31 | 30.03 | 5.80 | 0.016 | 0.19 | 4.79 | 0.18 |
| 2227_sd | 2.27 | 1.31 | 3.11 | 0.13 | 0.000 | 0.04 | 0.35 | 0.57 |
| 2227_sw | 42.39 | 1.31 | 23.85 | 3.94 | 0.011 | 0.17 | 3.66 | 0.20 |
| 222_1b | 20.41 | 1.40 | 8.57 | 2.11 | 0.006 | 0.25 | 3.25 | 0.34 |
| 222_1d | 4.12 | 1.40 | 3.63 | 0.47 | 0.001 | 0.13 | 1.13 | 0.52 |
| 222_1w | 47.74 | 1.40 | 30.21 | 6.99 | 0.019 | 0.23 | 5.75 | 0.18 |
| 222_2b | 22.82 | 1.57 | 12.53 | 3.92 | 0.011 | 0.31 | 4.98 | 0.28 |
| 222_2d | 2.51 | 1.57 | 3.71 | 0.41 | 0.001 | 0.11 | 0.97 | 0.52 |
| 222_2w | 40.82 | 1.57 | 27.55 | 7.51 | 0.021 | 0.27 | 6.45 | 0.19 |
| 222_sb | 20.23 | 1.55 | 8.16 | 3.68 | 0.010 | 0.45 | 5.72 | 0.34 |
| 222_sd | 3.26 | 1.55 | 2.86 | 0.28 | 0.001 | 0.10 | 0.74 | 0.59 |
| 222_sw | 35.92 | 1.55 | 21.54 | 9.13 | 0.025 | 0.42 | 8.76 | 0.21 |
| 2265_1b | 23.21 | 1.99 | 14.52 | 2.57 | 0.007 | 0.18 | 3.06 | 0.26 |
| 2265_1d | 3.65 | 1.99 | 4.06 | 0.44 | 0.001 | 0.11 | 0.98 | 0.50 |
| 2265_1w | 25.57 | 1.99 | 13.62 | 2.25 | 0.006 | 0.17 | 2.76 | 0.27 |
| 2265_2b | 20.71 | 1.94 | 12.80 | 1.79 | 0.005 | 0.14 | 2.28 | 0.28 |
| 2265_2d | 2.09 | 1.94 | 3.76 | 0.20 | 0.001 | 0.05 | 0.47 | 0.52 |
| 2265_2w | 24.72 | 1.94 | 14.56 | 2.08 | 0.006 | 0.14 | 2.47 | 0.26 |
| 2265_sb | 30.08 | 1.82 | 18.65 | 9.04 | 0.025 | 0.48 | 9.27 | 0.23 |
| 2265_sd | 3.87 | 1.82 | 3.81 | 0.28 | 0.001 | 0.07 | 0.65 | 0.51 |
| 2265_sw | 30.94 | 1.82 | 16.15 | 6.31 | 0.018 | 0.39 | 7.01 | 0.24 |

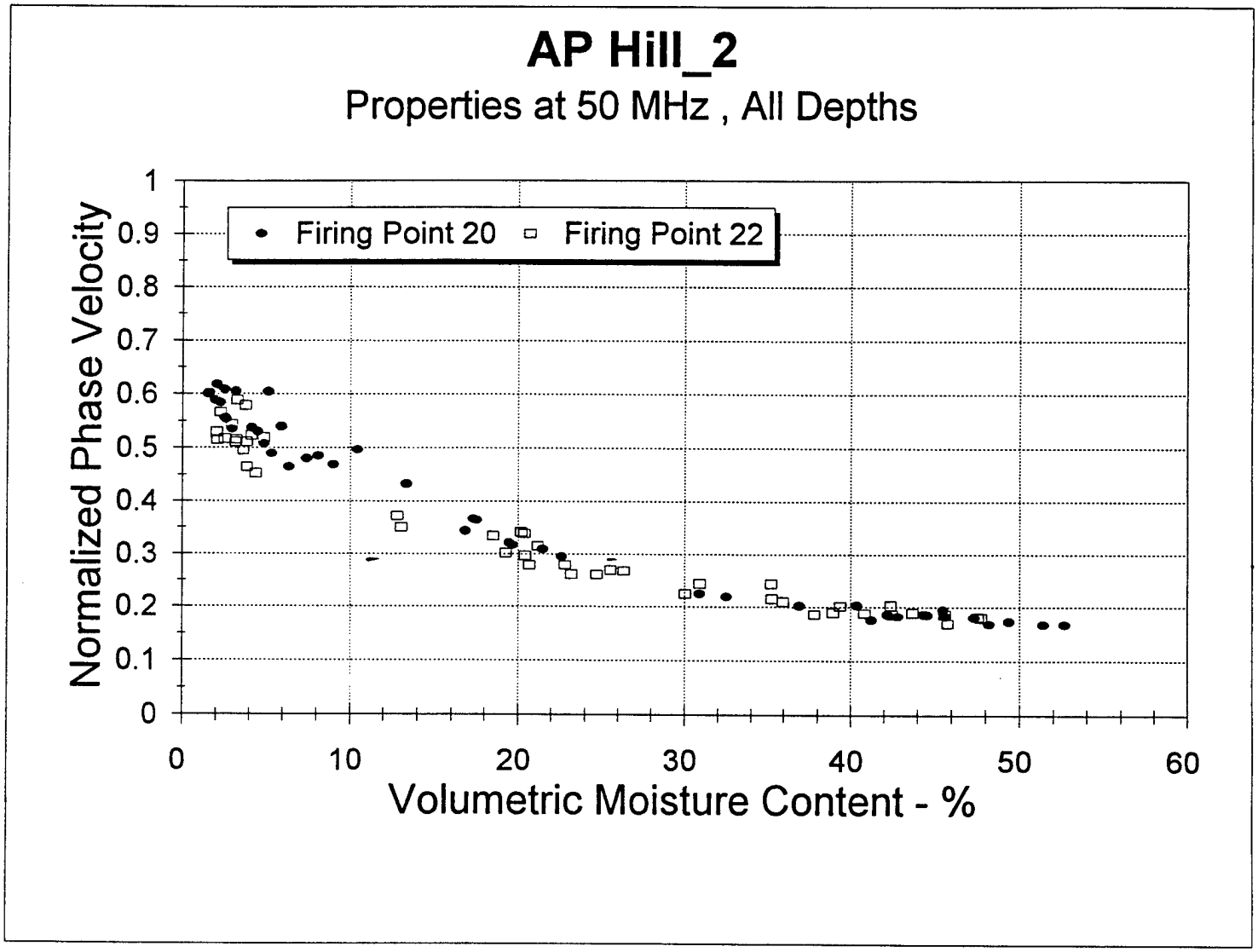

AP Hill_2
Properties at 50 MHz , All Depths
Firing Point 20
Firing Point 22
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50
60

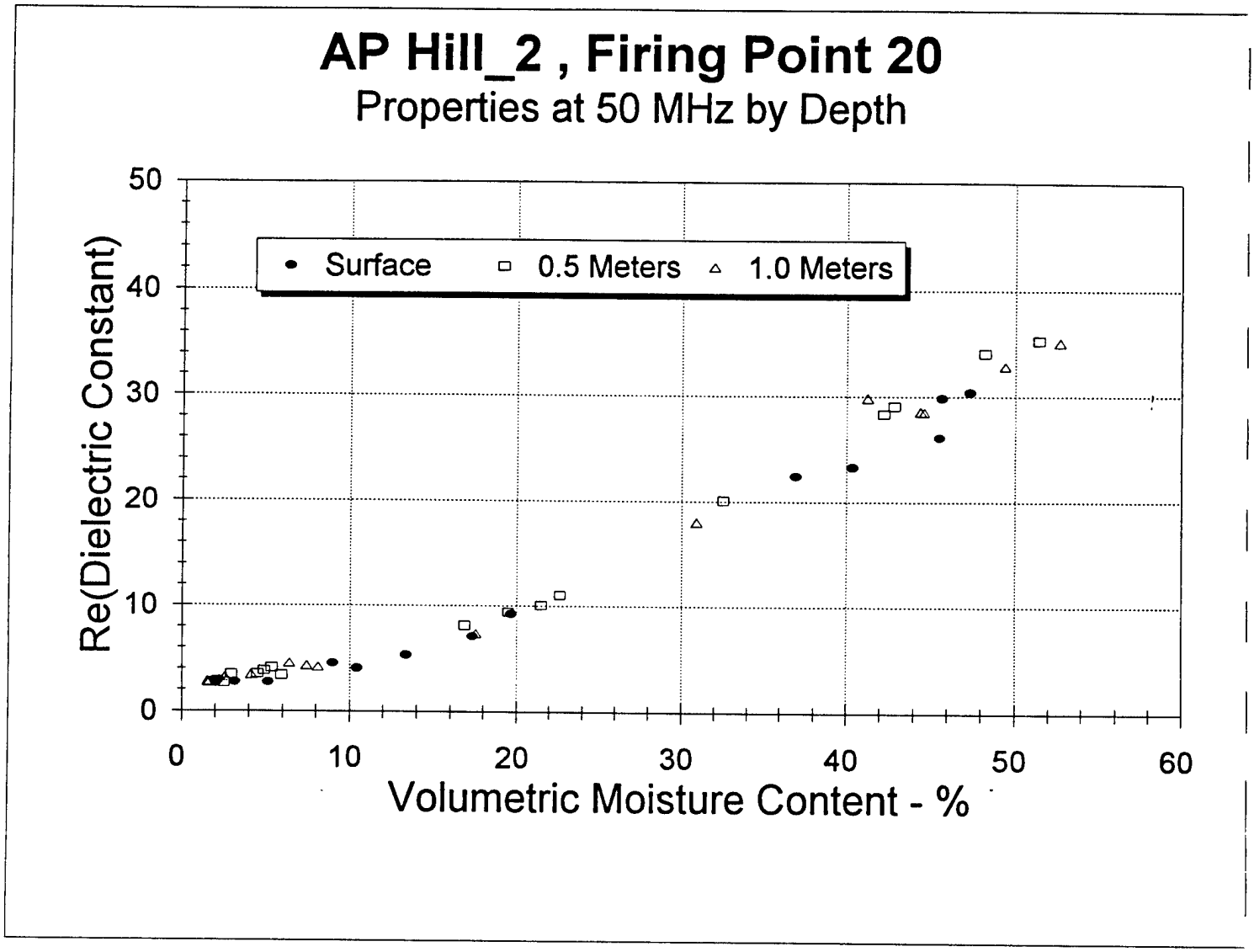

AP Hill_2
Properties at 50 MHz , All Depths
Firing Point 20
Firing Point 22
Im(Dielectric Constant)
0
10
20
30
40
50
0
10
20
30
40
50
60
Volumetric Moisture Content - %

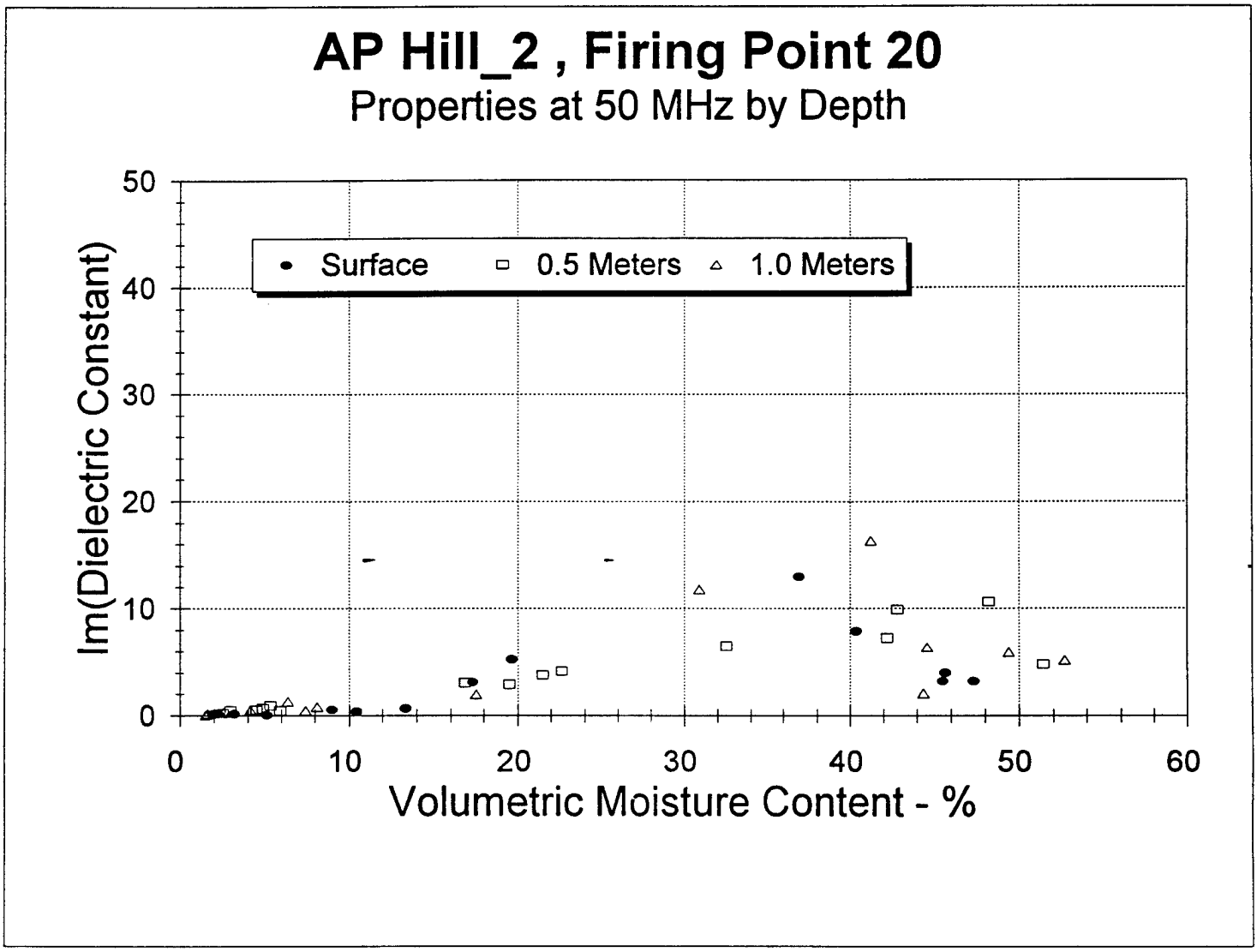

AP Hill_2
Properties at 50 MHz , All Depths
Firing Point 20
Firing Point 22
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

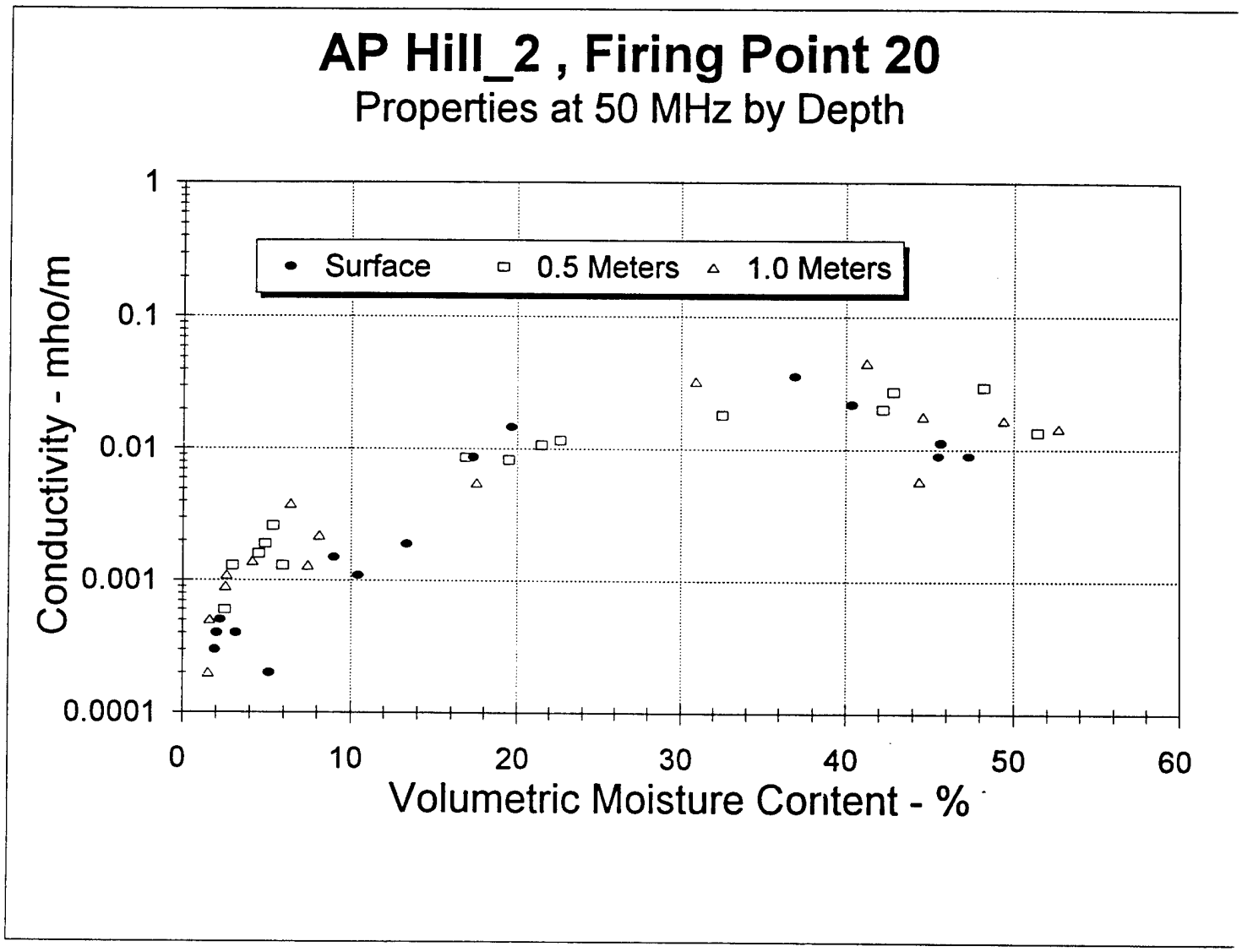

AP Hill_2
Properties at 50 MHz , All Depths
Firing Point 20
Firing Point 22
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

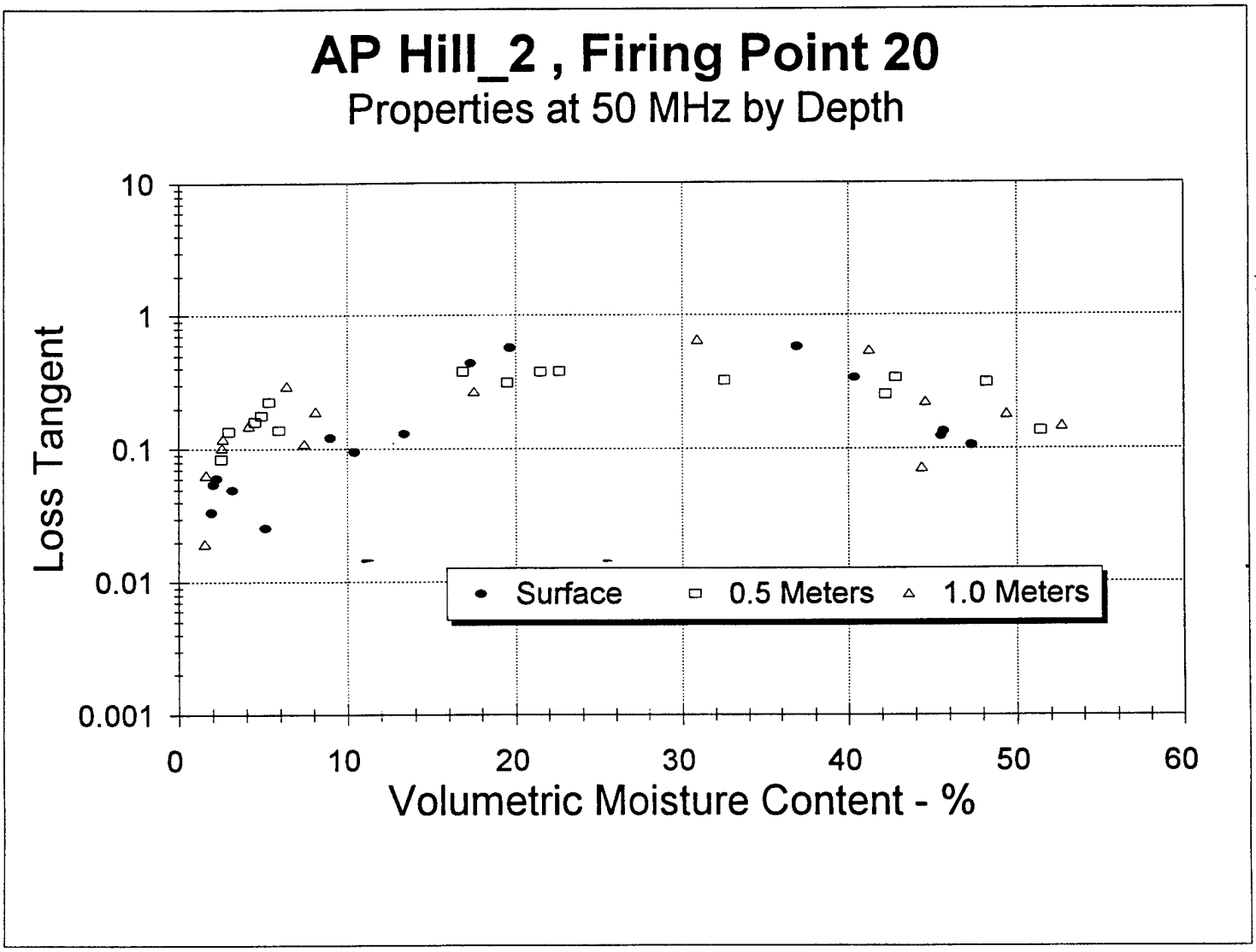

AP Hill_2
Properties at 50 MHz , All Depths
Firing Point 20
Firing Point 22
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
60
Volumetric Moisture Content - %


AP Hill_2
Properties at 50 MHz , All Depths
Normalized Phase Velocity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Firing Point 20
Firing Point 22
0
10
20
30
40
50
60
Volumetric Moisture Content - %


AP Hill_2 , Firing Point 20
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Re(Dielectric Constant)
0
10
20
30
40
50
0
10
20
30
40
50
60
Volumetric Moisture Content - %

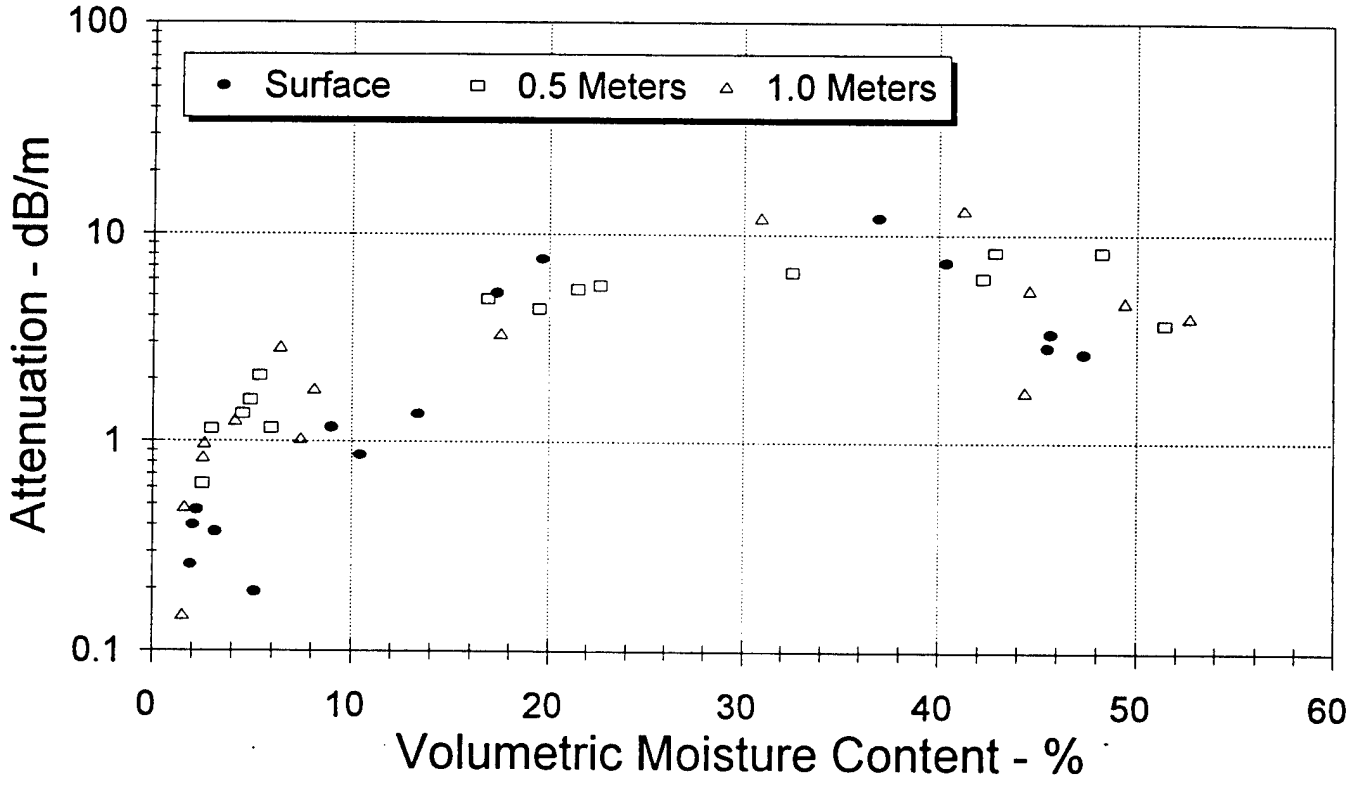

AP Hill_2 , Firing Point 20
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Im(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50
60

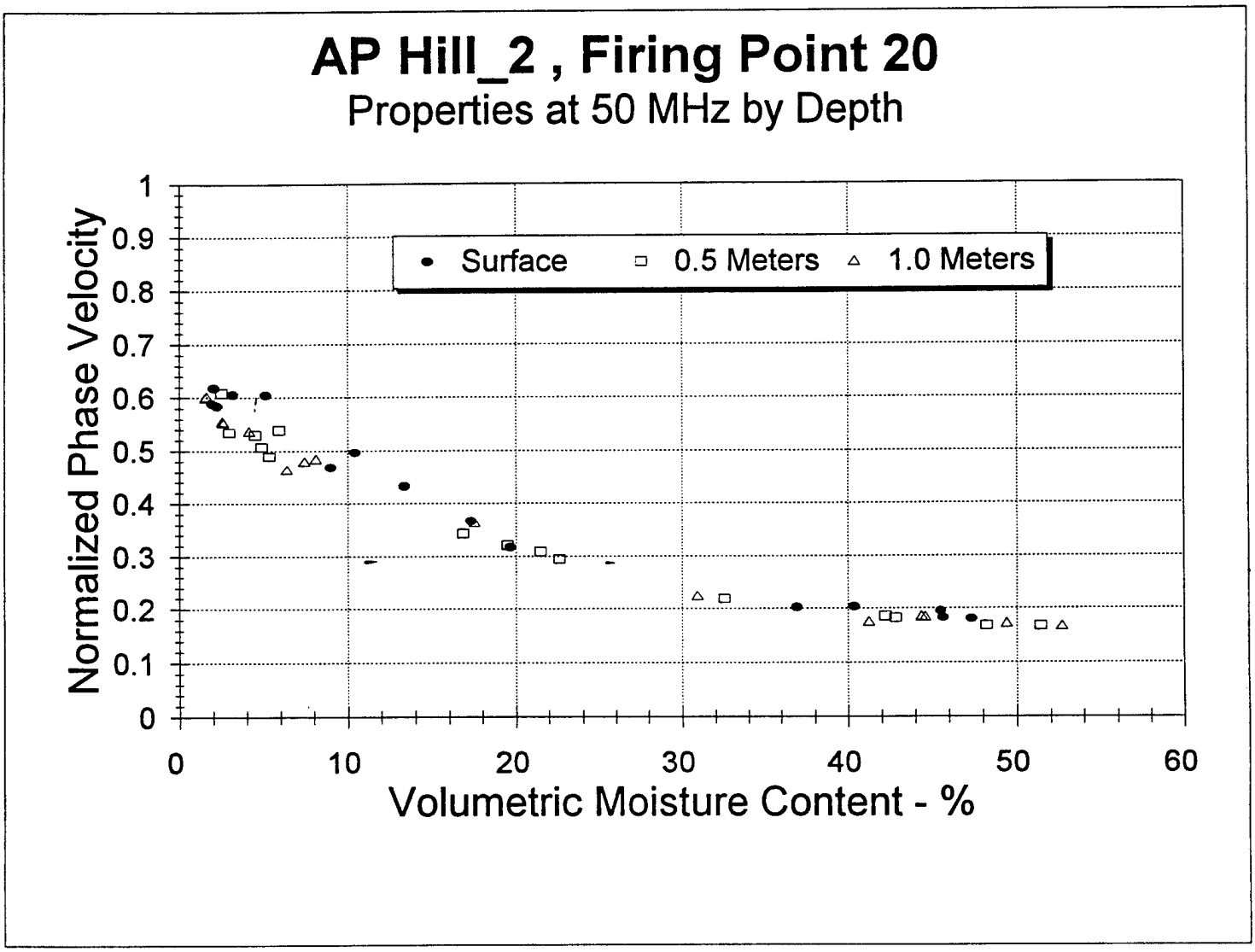

AP Hill_2 , Firing Point 20
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

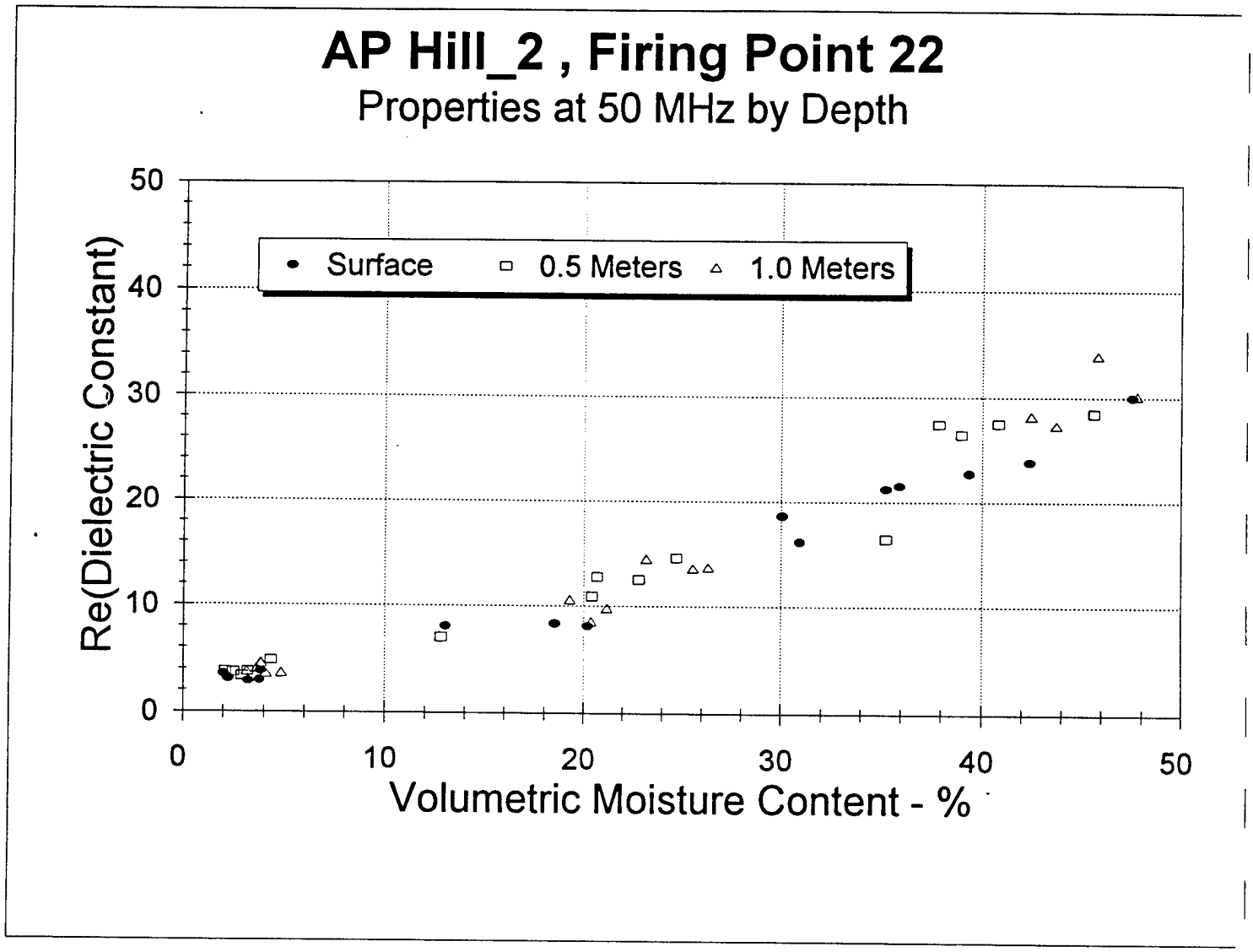

AP Hill_2 , Firing Point 20
Properties at 50 MHz by Depth
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters

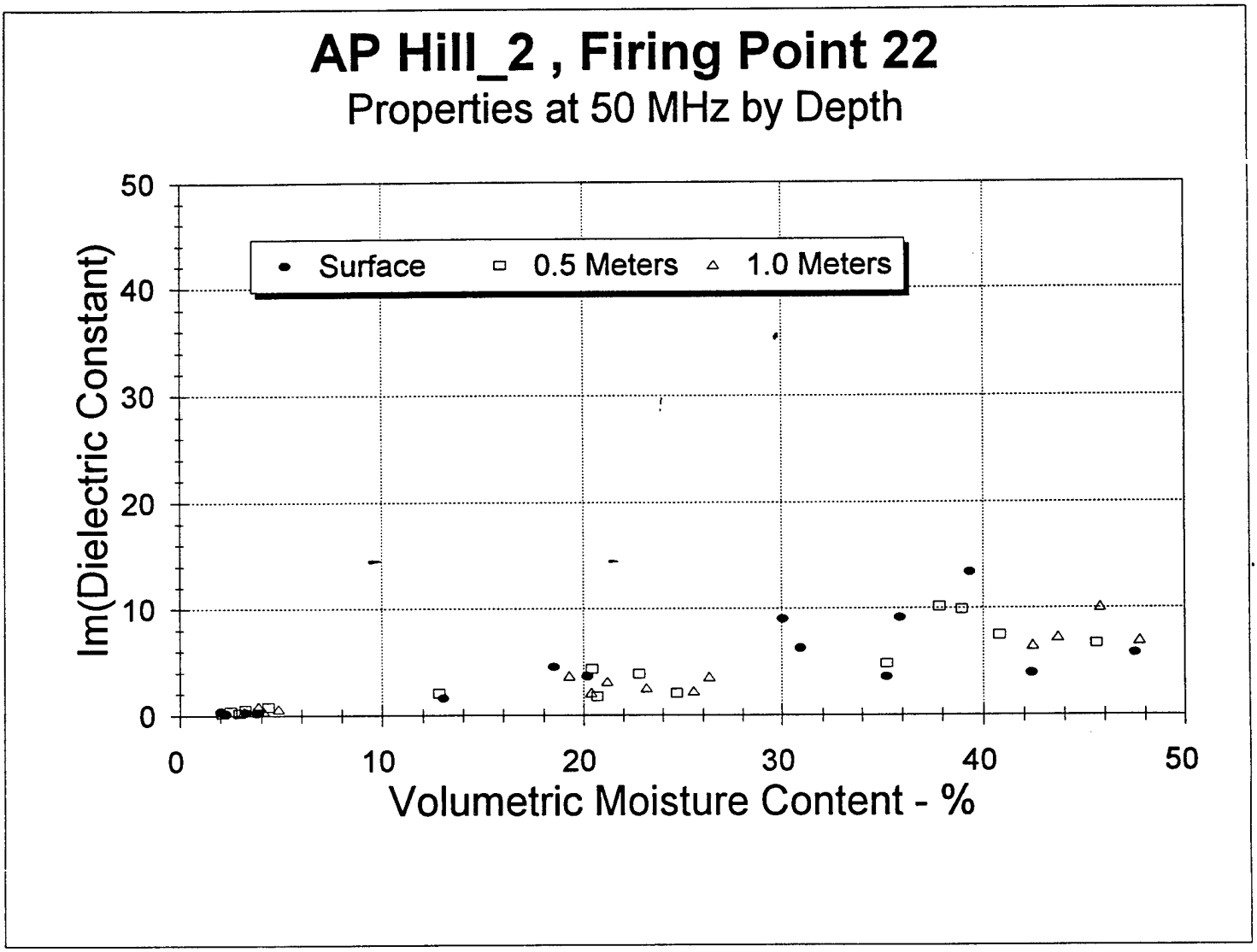
# AP Hill_2 , Firing Point 20

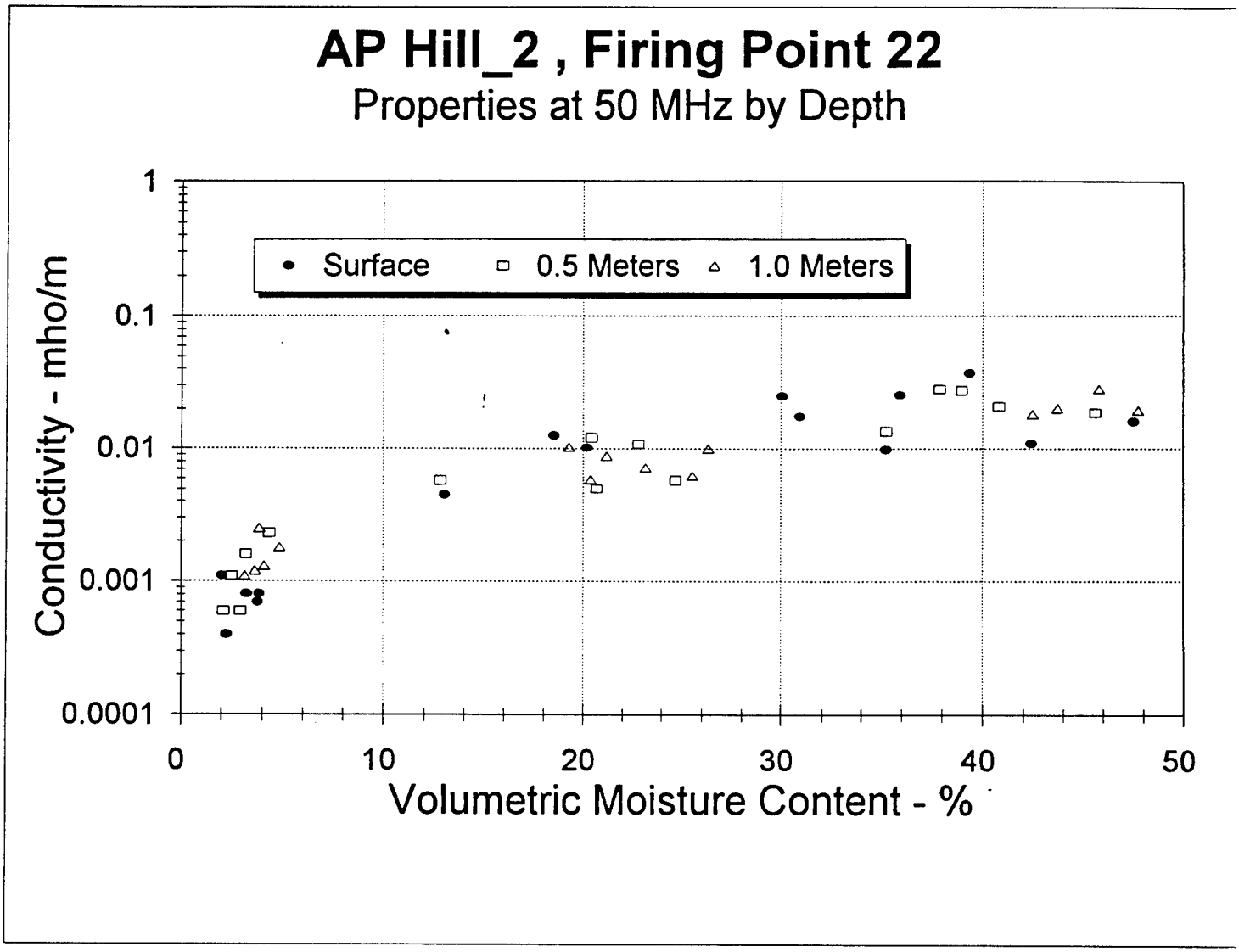
Properties at 50 MHz by Depth

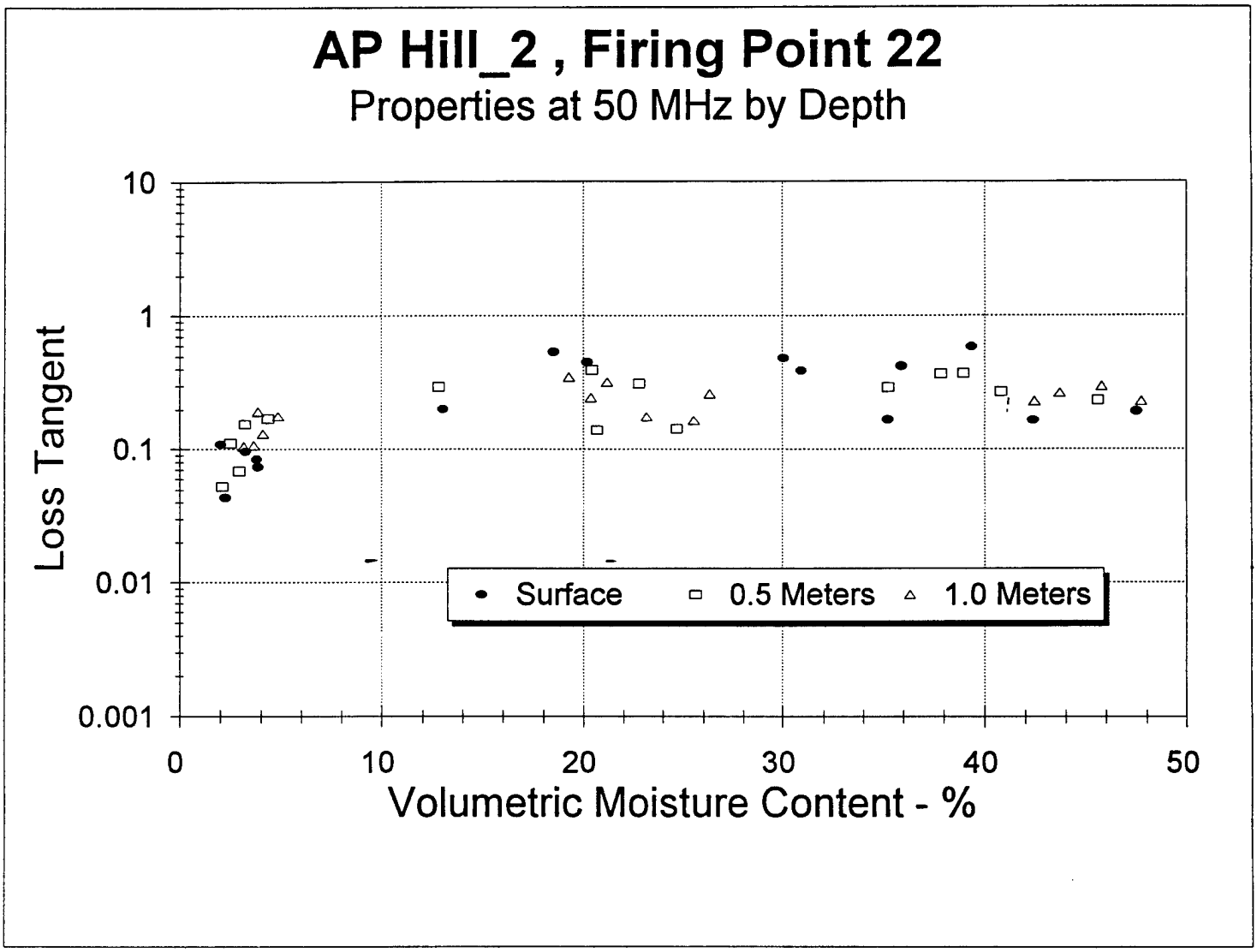


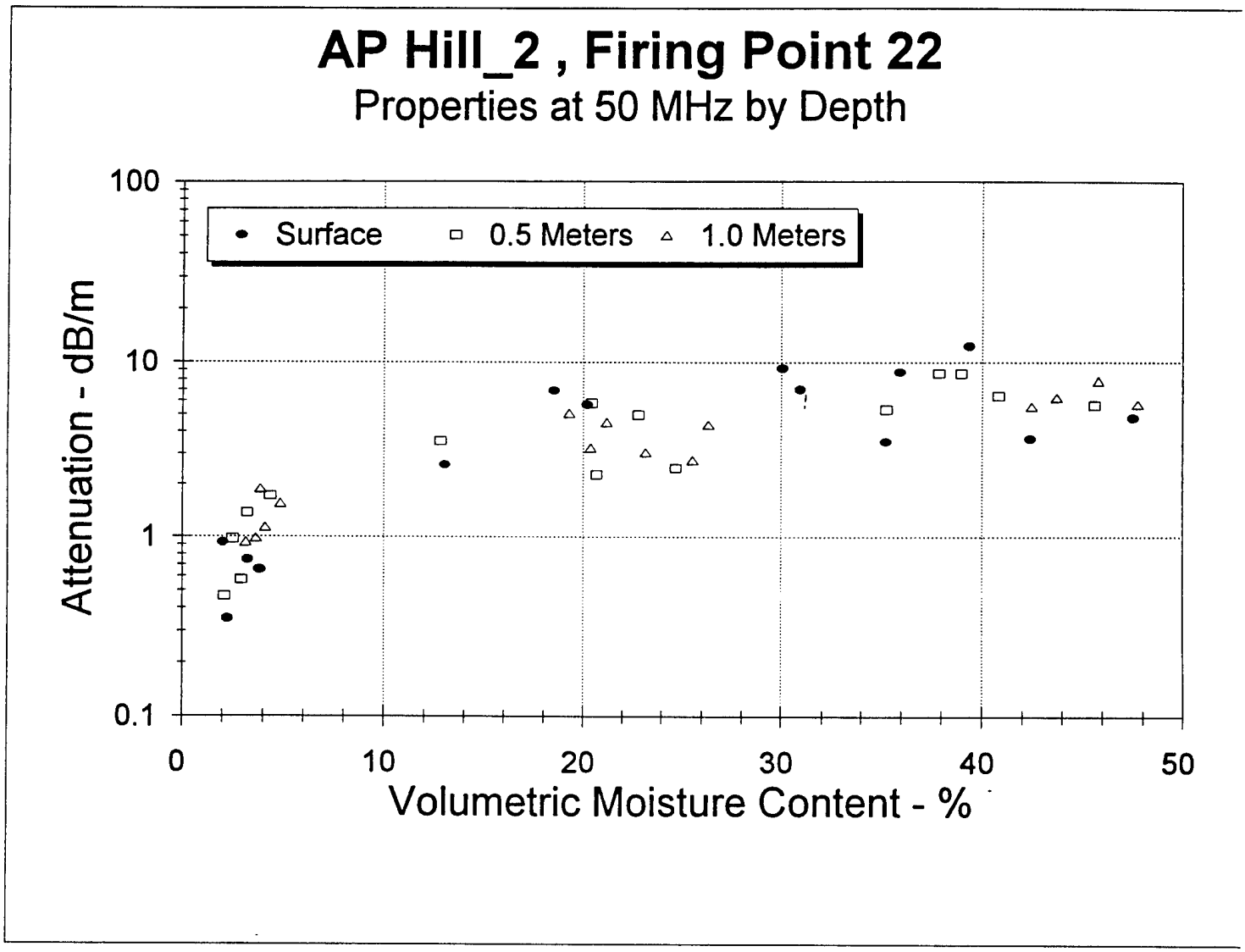

AP Hill_2 , Firing Point 20
Properties at 50 MHz by Depth
Normalized Phase Velocity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Surface
0.5 Meters
1.0 Meters
0
10
20
30
40
50
60
Volumetric Moisture Content - %

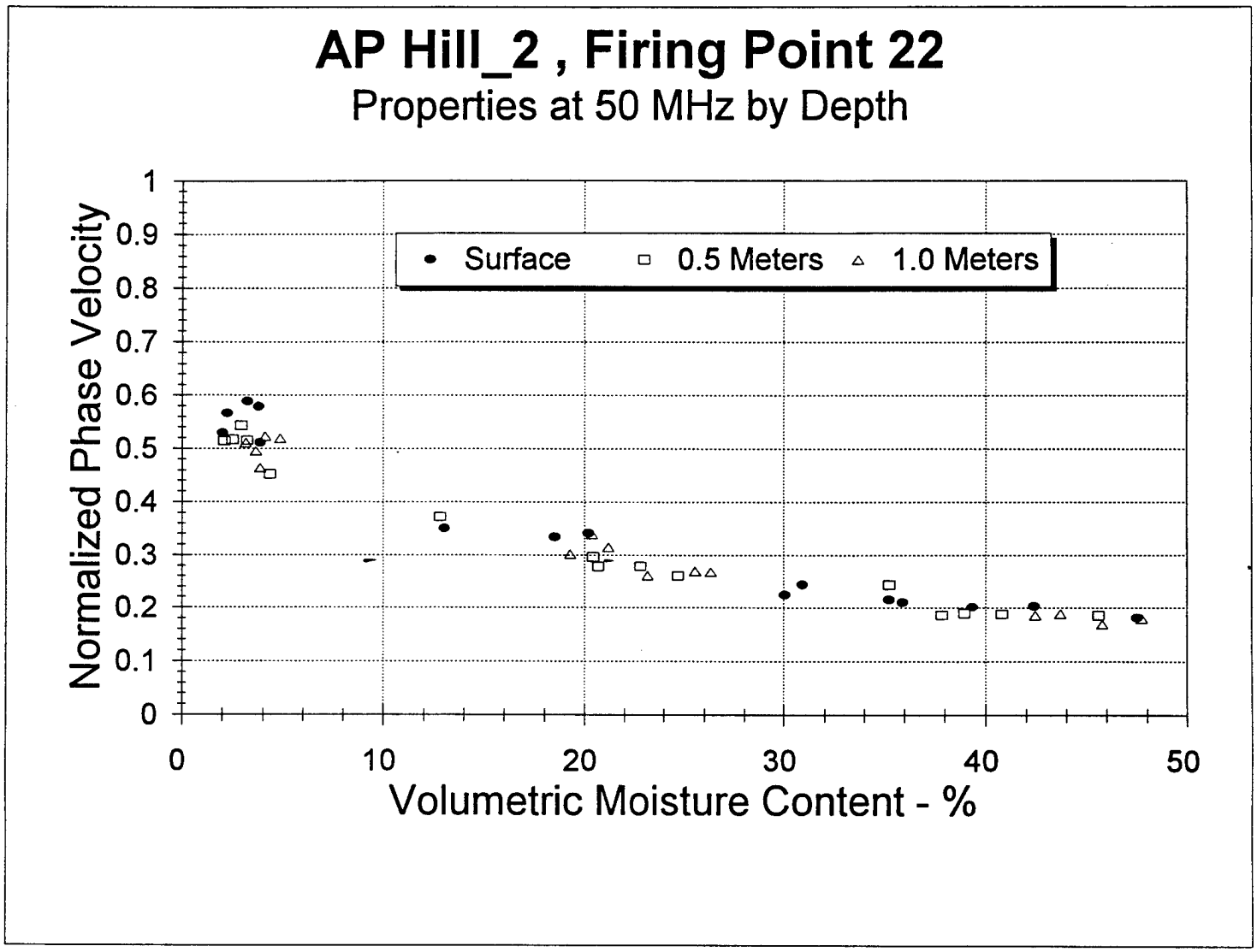

AP Hill_2 , Firing Point 22
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50


AP Hill_2 , Firing Point 22
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Im(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50


AP Hill_2 , Firing Point 22
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
Volumetric Moisture Content - %


AP Hill_2 , Firing Point 22
Properties at 50 MHz by Depth
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters


AP Hill_2 , Firing Point 22
Properties at 50 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
Volumetric Moisture Content - %


AP Hill_2 , Firing Point 22
Properties at 50 MHz by Depth
Normalized Phase Velocity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Surface
0.5 Meters
1.0 Meters
0
10
20
30
40
50
Volumetric Moisture Content - %

Fort A.P. Hill_2
Properties at 100 Mhz

Fort AP Hill_2 Soil Properties at 100 MHz

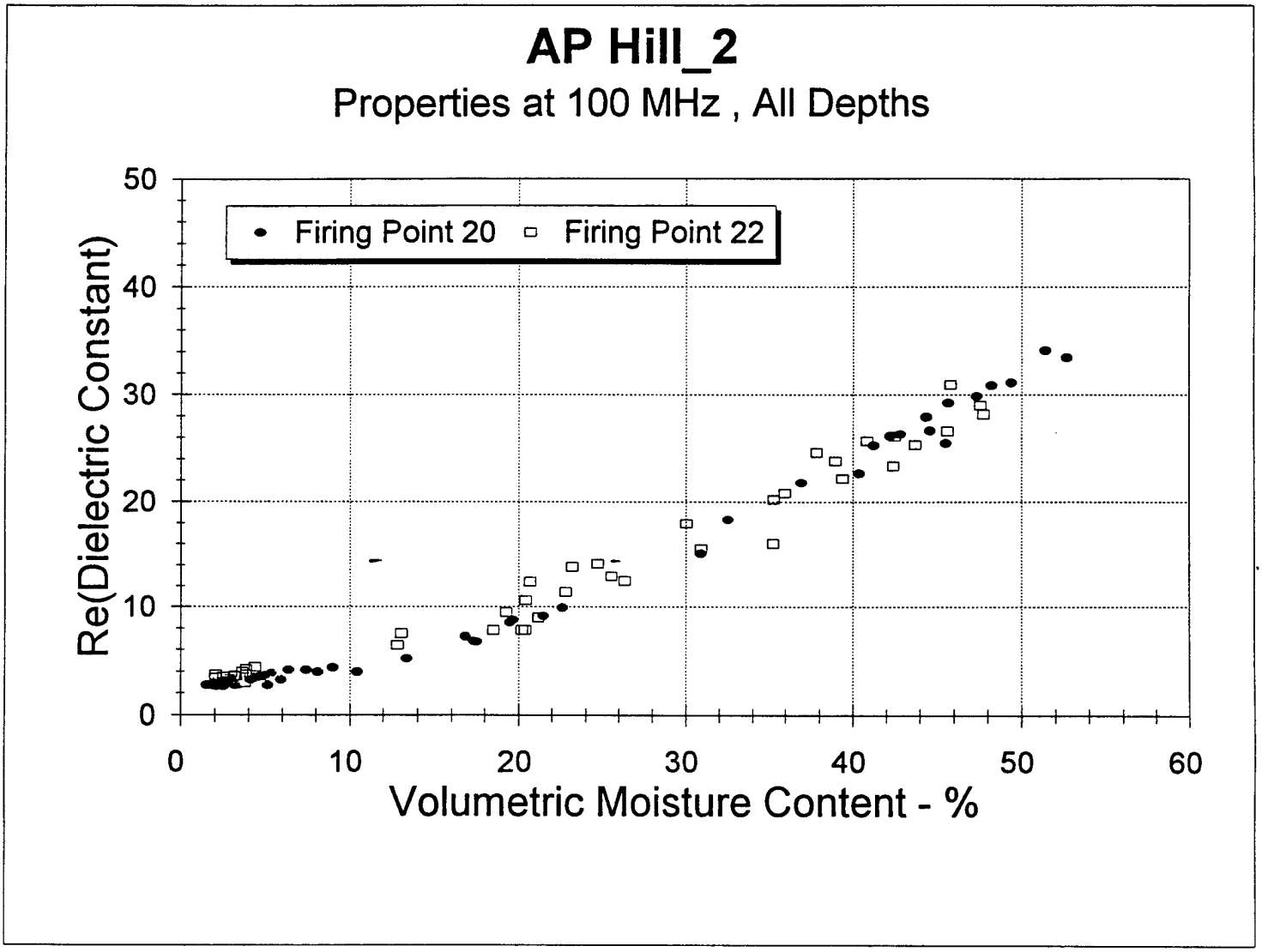
Firing Point 20

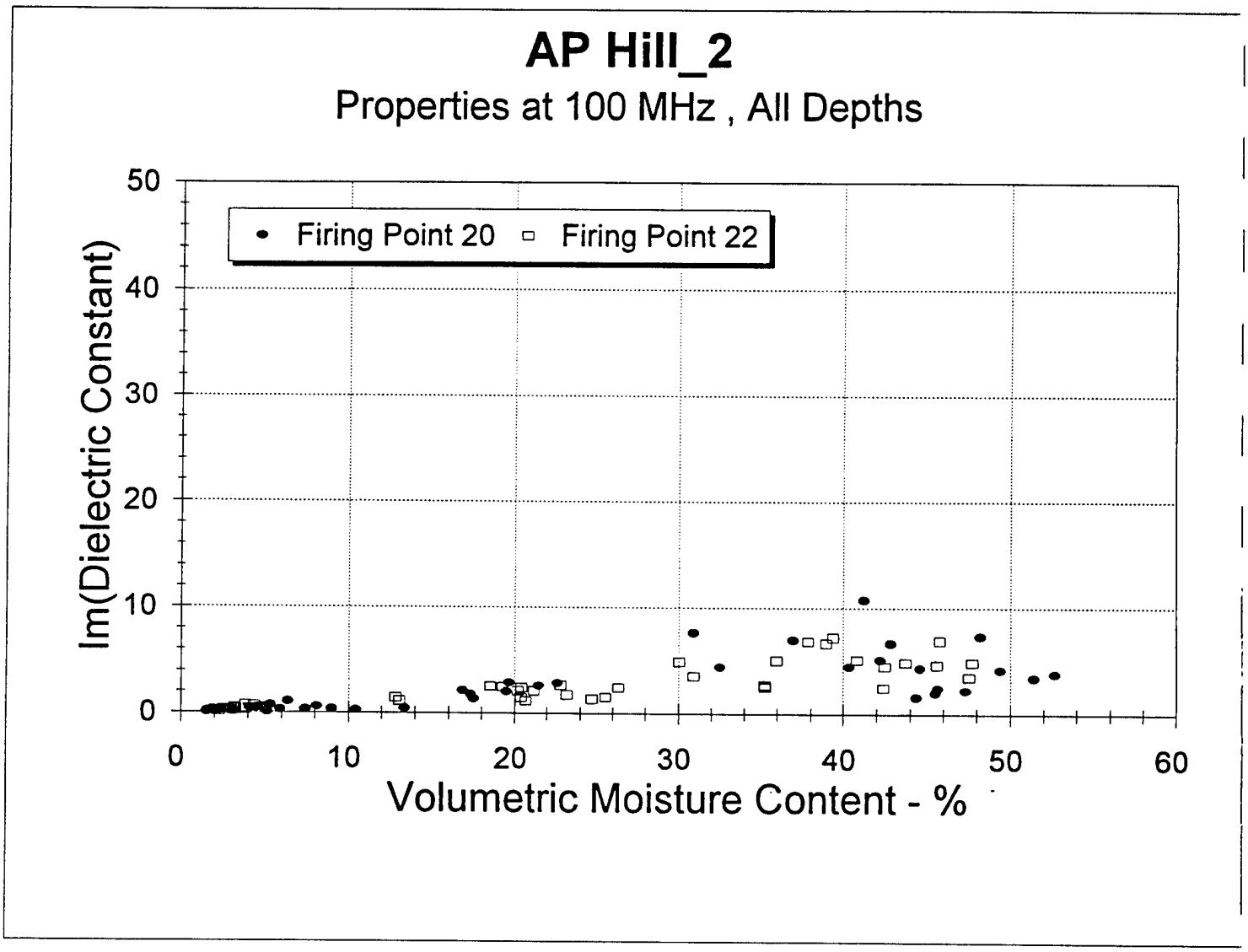
| File Name | Vol Moist | Dry Dens g/cc | Re(eps) | Im(eps) | Cond mho/m | Loss Tan | Attn dB/m | Norm Vel |
|---|---|---|---|---|---|---|---|---|
| 200_1b | 2.57 | 1.40 | 3.08 | 0.29 | 0.002 | 0.09 | 1.48 | 0.57 |
| 200_1d | 2.65 | 1.40 | 3.12 | 0.33 | 0.002 | 0.11 | 1.71 | 0.57 |
| 200_1w | 49.42 | 1.40 | 31.16 | 4.18 | 0.023 | 0.13 | 6.80 | 0.18 |
| 200_2b | 5.97 | 1.21 | 3.25 | 0.35 | 0.002 | 0.11 | 1.76 | 0.55 |
| 200_2d | 2.52 | 1.21 | 2.62 | 0.18 | 0.001 | 0.07 | 1.02 | 0.62 |
| 200_2w | 51.44 | 1.21 | 34.13 | 3.44 | 0.019 | 0.10 | 5.35 | 0.17 |
| 200_sb | 9.01 | 1.39 | 4.37 | 0.39 | 0.002 | 0.09 | 1.71 | 0.48 |
| 200_sd | 2.27 | 1.39 | 2.85 | 0.15 | 0.001 | 0.05 | 0.79 | 0.59 |
| 200_sw | 47.36 | 1.39 | 29.87 | 2.25 | 0.013 | 0.08 | 3.74 | 0.18 |
| 20122_1b | 30.94 | 1.53 | 15.11 | 7.65 | 0.043 | 0.51 | 17.39 | 0.25 |
| 20122_1d | 6.41 | 1.53 | 4.14 | 1.06 | 0.006 | 0.26 | 4.69 | 0.49 |
| 20122_1w | 41.25 | 1.53 | 25.32 | 10.82 | 0.060 | 0.43 | 19.14 | 0.19 |
| 20122_2b | 16.89 | 1.37 | 7.27 | 2.15 | 0.012 | 0.30 | 7.18 | 0.37 |
| 20122_2d | 2.98 | 1.37 | 3.31 | 0.39 | 0.002 | 0.12 | 1.97 | 0.55 |
| 20122_2w | 48.22 | 1.37 | 30.92 | 7.37 | 0.041 | 0.24 | 11.97 | 0.18 |
| 20122_sb | 17.37 | 1.47 | 6.83 | 1.76 | 0.010 | 0.26 | 6.09 | 0.38 |
| 20122_sd | 3.19 | 1.47 | 2.75 | 0.12 | 0.001 | 0.04 | 0.67 | 0.60 |
| 20122_sw | 40.39 | 1.47 | 22.71 | 4.49 | 0.025 | 0.20 | 8.52 | 0.21 |
| 20123_1b | 8.11 | 1.33 | 3.98 | 0.60 | 0.003 | 0.15 | 2.71 | 0.50 |
| 20123_1d | 1.61 | 1.33 | 2.72 | 0.16 | 0.001 | 0.06 | 0.89 | 0.61 |
| 20123_1w | 52.69 | 1.33 | 33.49 | 3.83 | 0.021 | 0.11 | 6.02 | 0.17 |
| 20123_2b | 21.49 | 1.66 | 9.15 | 2.63 | 0.015 | 0.29 | 7.82 | 0.33 |
| 20123_2d | 4.55 | 1.66 | 3.42 | 0.47 | 0.003 | 0.14 | 2.29 | 0.54 |
| 20123_2w | 32.55 | 1.66 | 18.31 | 4.44 | 0.025 | 0.24 | 9.38 | 0.23 |
| 20123_sb | 19.71 | 1.54 | 8.78 | 2.92 | 0.016 | 0.33 | 8.86 | 0.33 |
| 20123_sd | 1.95 | 1.54 | 2.88 | 0.09 | 0.001 | 0.03 | 0.49 | 0.59 |
| 20123_sw | 36.96 | 1.54 | 21.80 | 7.00 | 0.039 | 0.32 | 13.46 | 0.21 |
| 2027_1b | 7.44 | 1.53 | 4.15 | 0.34 | 0.002 | 0.08 | 1.51 | 0.49 |
| 2027_1d | 1.54 | 1.53 | 2.76 | 0.05 | 0.000 | 0.02 | 0.28 | 0.60 |
| 2027_1w | 44.38 | 1.53 | 27.96 | 1.65 | 0.009 | 0.06 | 2.83 | 0.19 |
| 2027_2b | 22.63 | 1.53 | 9.94 | 2.88 | 0.016 | 0.29 | 8.23 | 0.31 |
| 2027_2d | 5.34 | 1.53 | 3.84 | 0.73 | 0.004 | 0.19 | 3.37 | 0.51 |
| 2027_2w | 42.86 | 1.53 | 26.36 | 6.69 | 0.037 | 0.25 | 11.76 | 0.19 |
| 2027_sb | 10.49 | 1.44 | 3.95 | 0.26 | 0.002 | 0.07 | 1.21 | 0.50 |
| 2027_sd | 5.16 | 1.44 | 2.75 | 0.07 | 0.000 | 0.03 | 0.40 | 0.60 |
| 2027_sw | 45.55 | 1.44 | 25.55 | 2.02 | 0.011 | 0.08 | 3.64 | 0.20 |
| 2065_1b | 17.55 | 1.47 | 6.79 | 1.39 | 0.008 | 0.20 | 4.83 | 0.38 |
| 2065_1d | 4.15 | 1.47 | 3.28 | 0.42 | 0.002 | 0.13 | 2.13 | 0.55 |
| 2065_1w | 44.58 | 1.47 | 26.68 | 4.39 | 0.024 | 0.16 | 7.70 | 0.19 |
| 2065_2b | 19.52 | 1.48 | 8.58 | 2.10 | 0.012 | 0.25 | 6.49 | 0.34 |
| 2065_2d | 4.91 | 1.48 | 3.61 | 0.55 | 0.003 | 0.15 | 2.65 | 0.53 |
| 2065_2w | 42.22 | 1.48 | 26.19 | 5.15 | 0.029 | 0.20 | 9.10 | 0.19 |
| 2065_sb | 13.39 | 1.37 | 5.20 | 0.44 | 0.002 | 0.08 | 1.75 | 0.44 |
| 2065_sd | 2.09 | 1.37 | 2.62 | 0.13 | 0.001 | 0.05 | 0.71 | 0.62 |
| 2065_sw | 45.70 | 1.37 | 29.26 | 2.49 | 0.014 | 0.09 | 4.18 | 0.18 |

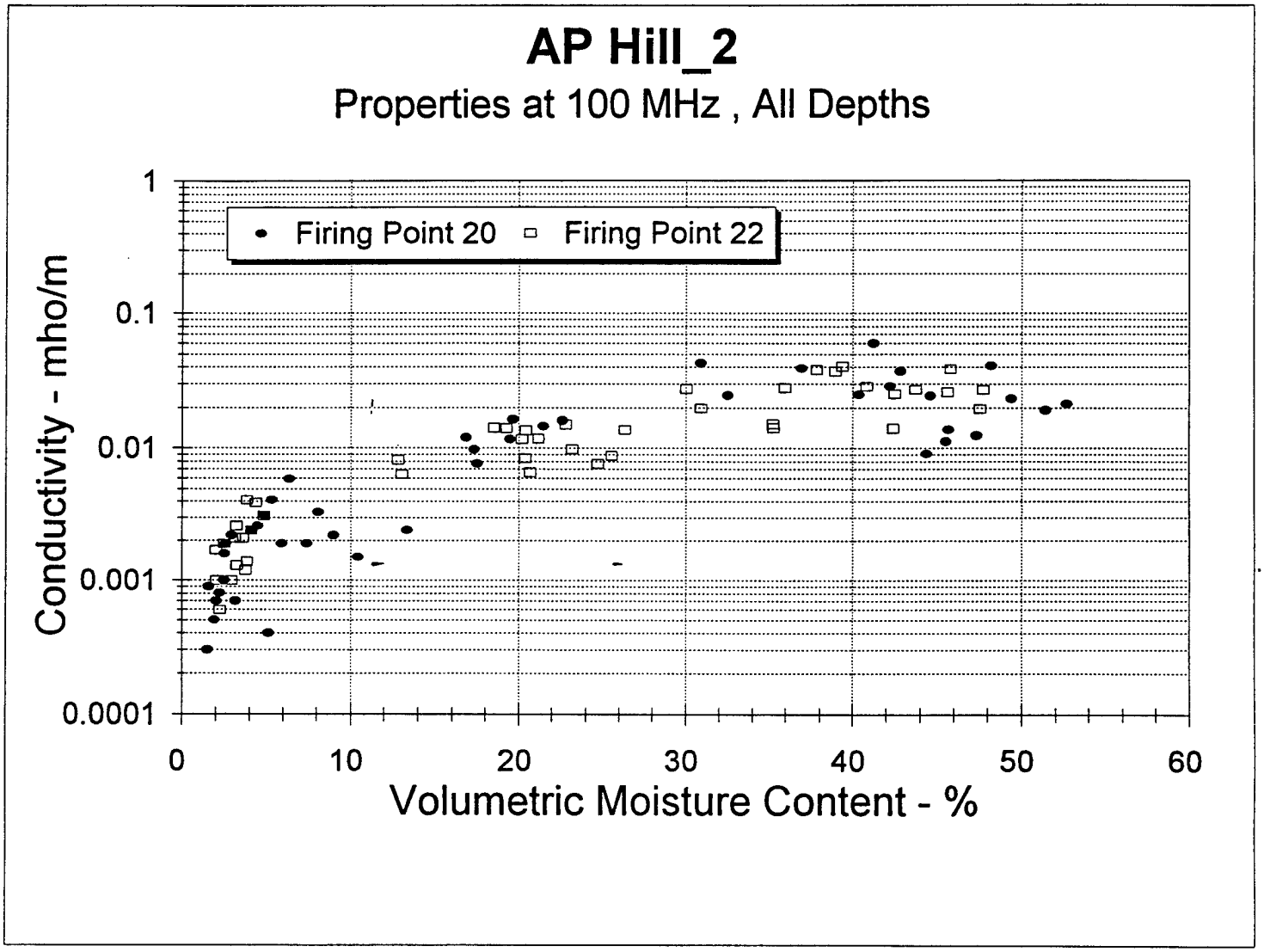
Fort AP Hill_2 Soil Properties at 100 MHz

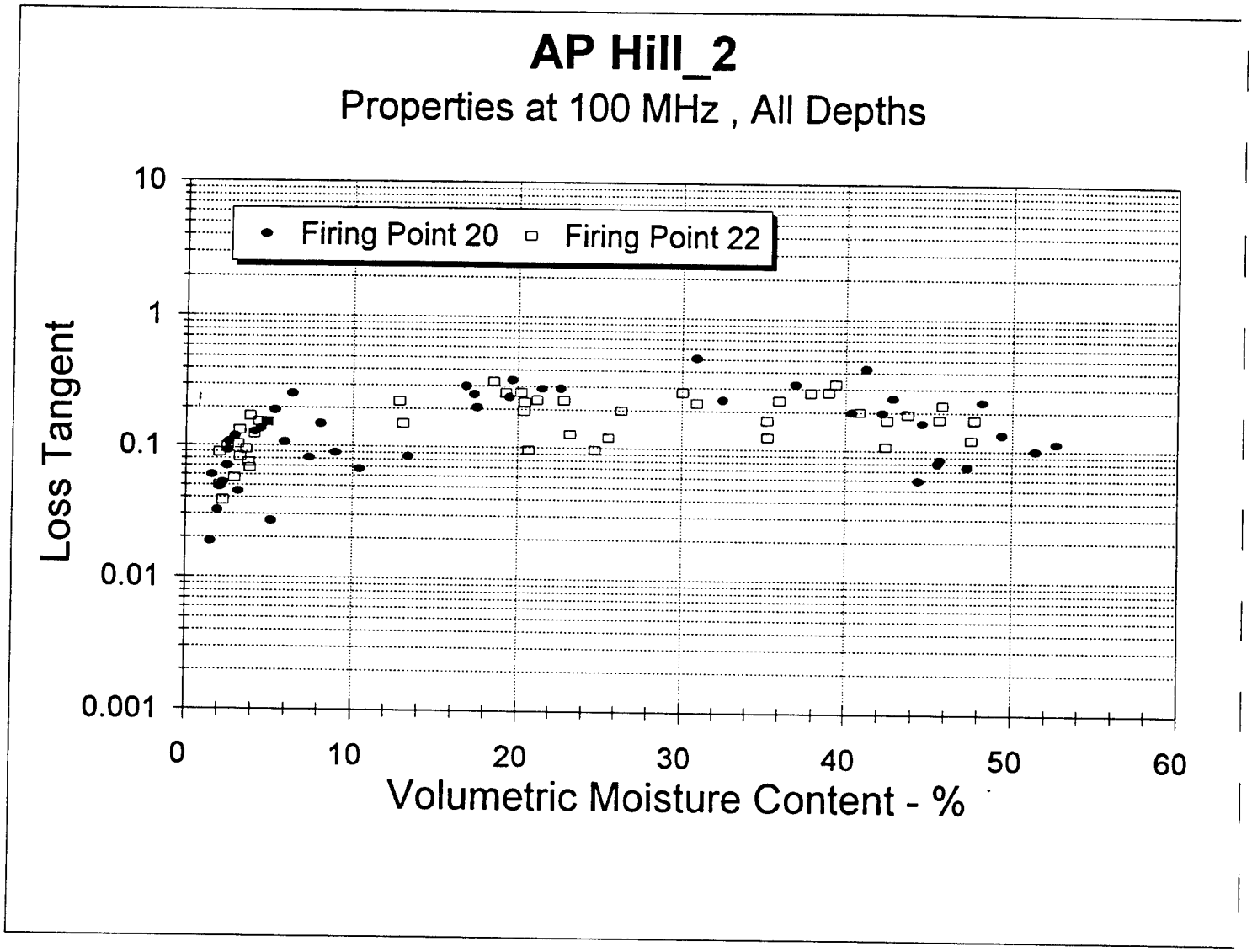
Firing Point 22

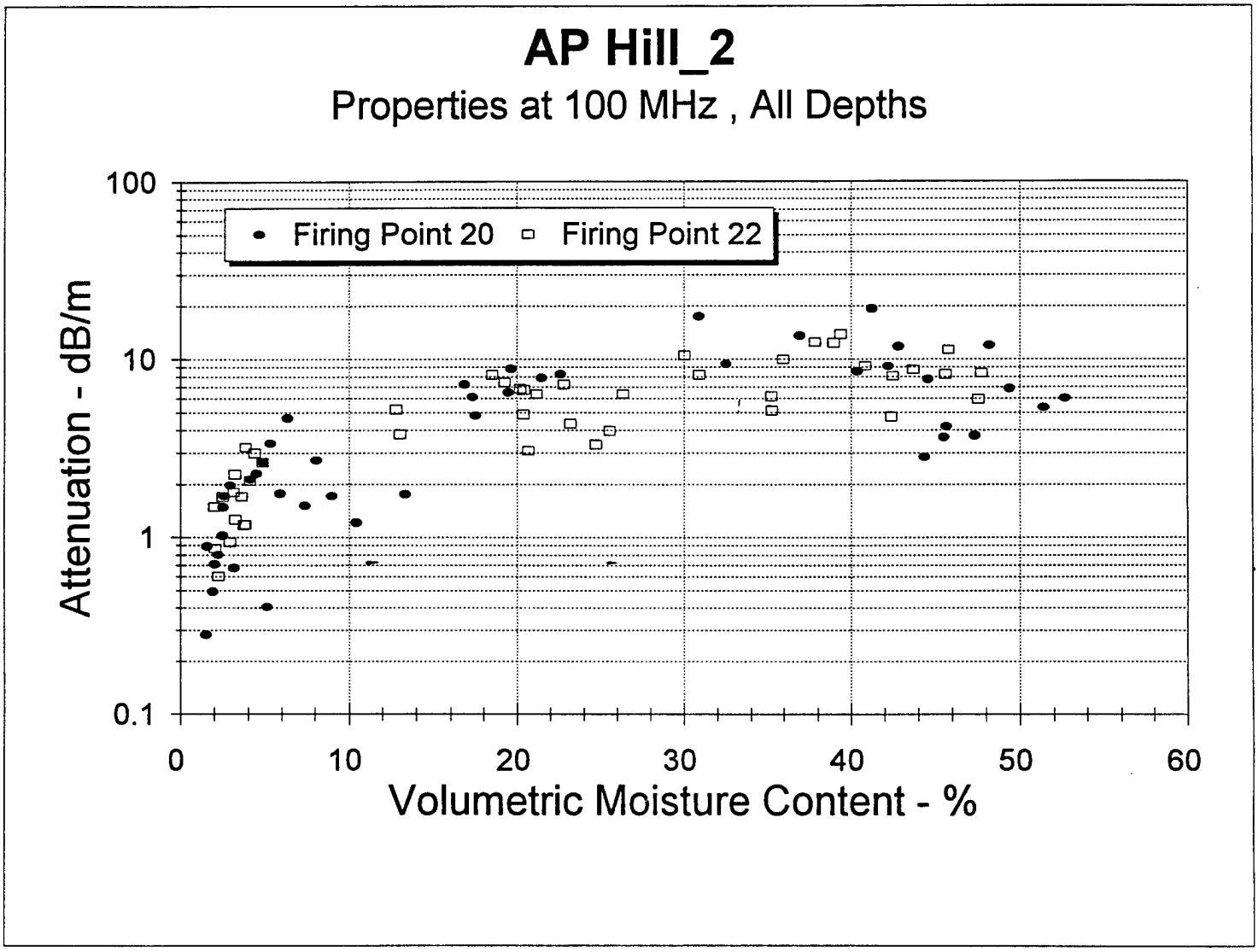
| File Name | Vol Moist | Dry Dens g/cc | Re(eps) | Im(eps) | Cond mho/m | Loss Tan | Attn dB/m | Norm Vel |
|---|---|---|---|---|---|---|---|---|
| 22122_1b | 19.30 | 1.53 | 9.55 | 2.53 | 0.014 | 0.27 | 7.39 | 0.32 |
| 22122_1d | 3.88 | 1.53 | 4.25 | 0.73 | 0.004 | 0.17 | 3.20 | 0.48 |
| 22122_1w | 45.79 | 1.53 | 30.98 | 6.96 | 0.039 | 0.22 | 11.31 | 0.18 |
| 22122_2b | 20.45 | 1.83 | 10.65 | 2.42 | 0.014 | 0.23 | 6.71 | 0.30 |
| 22122_2d | 2.94 | 1.83 | 3.33 | 0.19 | 0.001 | 0.06 | 0.94 | 0.55 |
| 22122_2w | 35.24 | 1.83 | 16.06 | 2.73 | 0.015 | 0.17 | 6.18 | 0.25 |
| 22122_sb | 13.05 | 1.69 | 7.58 | 1.15 | 0.006 | 0.15 | 3.80 | 0.36 |
| 22122_sd | 2.04 | 1.69 | 3.40 | 0.30 | 0.002 | 0.09 | 1.49 | 0.54 |
| 22122_sw | 35.25 | 1.69 | 20.23 | 2.55 | 0.014 | 0.13 | 5.15 | 0.22 |
| 22123_1b | 21.20 | 1.53 | 9.01 | 2.11 | 0.012 | 0.23 | 6.36 | 0.33 |
| 22123_1d | 4.87 | 1.53 | 3.58 | 0.55 | 0.003 | 0.15 | 2.65 | 0.53 |
| 22123_1w | 43.69 | 1.53 | 25.41 | 4.87 | 0.027 | 0.19 | 8.75 | 0.20 |
| 22123_2b | 12.82 | 1.51 | 6.47 | 1.47 | 0.008 | 0.23 | 5.21 | 0.39 |
| 22123_2d | 3.22 | 1.51 | 3.57 | 0.47 | 0.003 | 0.13 | 2.28 | 0.53 |
| 22123_2w | 45.59 | 1.51 | 26.65 | 4.68 | 0.026 | 0.18 | 8.21 | 0.19 |
| 22123_sb | 18.55 | 1.55 | 7.89 | 2.55 | 0.014 | 0.32 | 8.15 | 0.35 |
| 22123_sd | 3.80 | 1.55 | 3.00 | 0.22 | 0.001 | 0.07 | 1.17 | 0.58 |
| 22123_sw | 39.36 | 1.55 | 22.20 | 7.26 | 0.040 | 0.33 | 13.83 | 0.21 |
| 2227_1b | 26.33 | 1.51 | 12.54 | 2.49 | 0.014 | 0.20 | 6.36 | 0.28 |
| 2227_1d | 3.15 | 1.51 | 3.60 | 0.37 | 0.002 | 0.10 | 1.79 | 0.53 |
| 2227_1w | 42.47 | 1.51 | 26.19 | 4.54 | 0.025 | 0.17 | 8.03 | 0.19 |
| 2227_2b | 37.85 | 1.66 | 24.68 | 6.87 | 0.038 | 0.28 | 12.46 | 0.20 |
| 2227_2d | 4.37 | 1.66 | 4.47 | 0.70 | 0.004 | 0.16 | 2.98 | 0.47 |
| 2227_2w | 38.96 | 1.66 | 23.87 | 6.70 | 0.037 | 0.28 | 12.36 | 0.20 |
| 2227_sb | 47.54 | 1.31 | 29.04 | 3.54 | 0.020 | 0.12 | 5.97 | 0.19 |
| 2227_sd | 2.27 | 1.31 | 3.04 | 0.12 | 0.001 | 0.04 | 0.60 | 0.57 |
| 2227_sw | 42.39 | 1.31 | 23.40 | 2.54 | 0.014 | 0.11 | 4.76 | 0.21 |
| 222_1b | 20.41 | 1.40 | 7.86 | 1.52 | 0.008 | 0.19 | 4.89 | 0.36 |
| 222_1d | 4.12 | 1.40 | 3.43 | 0.43 | 0.002 | 0.12 | 2.09 | 0.54 |
| 222_1w | 47.74 | 1.40 | 28.20 | 4.89 | 0.027 | 0.17 | 8.34 | 0.19 |
| 222_2b | 22.82 | 1.57 | 11.46 | 2.70 | 0.015 | 0.24 | 7.19 | 0.29 |
| 222_2d | 2.51 | 1.57 | 3.53 | 0.35 | 0.002 | 0.10 | 1.69 | 0.53 |
| 222_2w | 40.82 | 1.57 | 25.76 | 5.13 | 0.029 | 0.20 | 9.16 | 0.20 |
| 222_sb | 20.23 | 1.55 | 7.85 | 2.11 | 0.012 | 0.27 | 6.79 | 0.35 |
| 222_sd | 3.26 | 1.55 | 2.89 | 0.24 | 0.001 | 0.08 | 1.26 | 0.59 |
| 222_sw | 35.92 | 1.55 | 20.87 | 5.05 | 0.028 | 0.24 | 9.98 | 0.22 |
| 2265_1b | 23.21 | 1.99 | 13.82 | 1.78 | 0.010 | 0.13 | 4.35 | 0.27 |
| 2265_1d | 3.65 | 1.99 | 3.97 | 0.37 | 0.002 | 0.09 | 1.70 | 0.50 |
| 2265_1w | 25.57 | 1.99 | 12.98 | 1.58 | 0.009 | 0.12 | 3.97 | 0.28 |
| 2265_2b | 20.71 | 1.94 | 12.42 | 1.19 | 0.007 | 0.10 | 3.08 | 0.28 |
| 2265_2d | 2.09 | 1.94 | 3.70 | 0.18 | 0.001 | 0.05 | 0.87 | 0.52 |
| 2265_2w | 24.72 | 1.94 | 14.12 | 1.38 | 0.008 | 0.10 | 3.33 | 0.27 |
| 2265_sb | 30.08 | 1.82 | 17.95 | 4.95 | 0.028 | 0.28 | 10.52 | 0.23 |
| 2265_sd | 3.87 | 1.82 | 3.72 | 0.25 | 0.001 | 0.07 | 1.18 | 0.52 |
| 2265_sw | 30.94 | 1.82 | 15.59 | 3.57 | 0.020 | 0.23 | 8.17 | 0.25 |


AP Hill_2
Properties at 100 MHz , All Depths
Firing Point 20
Firing Point 22
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50
60


AP Hill_2
Properties at 100 MHz , All Depths
Firing Point 20
Firing Point 22
Im(Dielectric Constant)
0
10
20
30
40
50
0
10
20
30
40
50
60
Volumetric Moisture Content - %

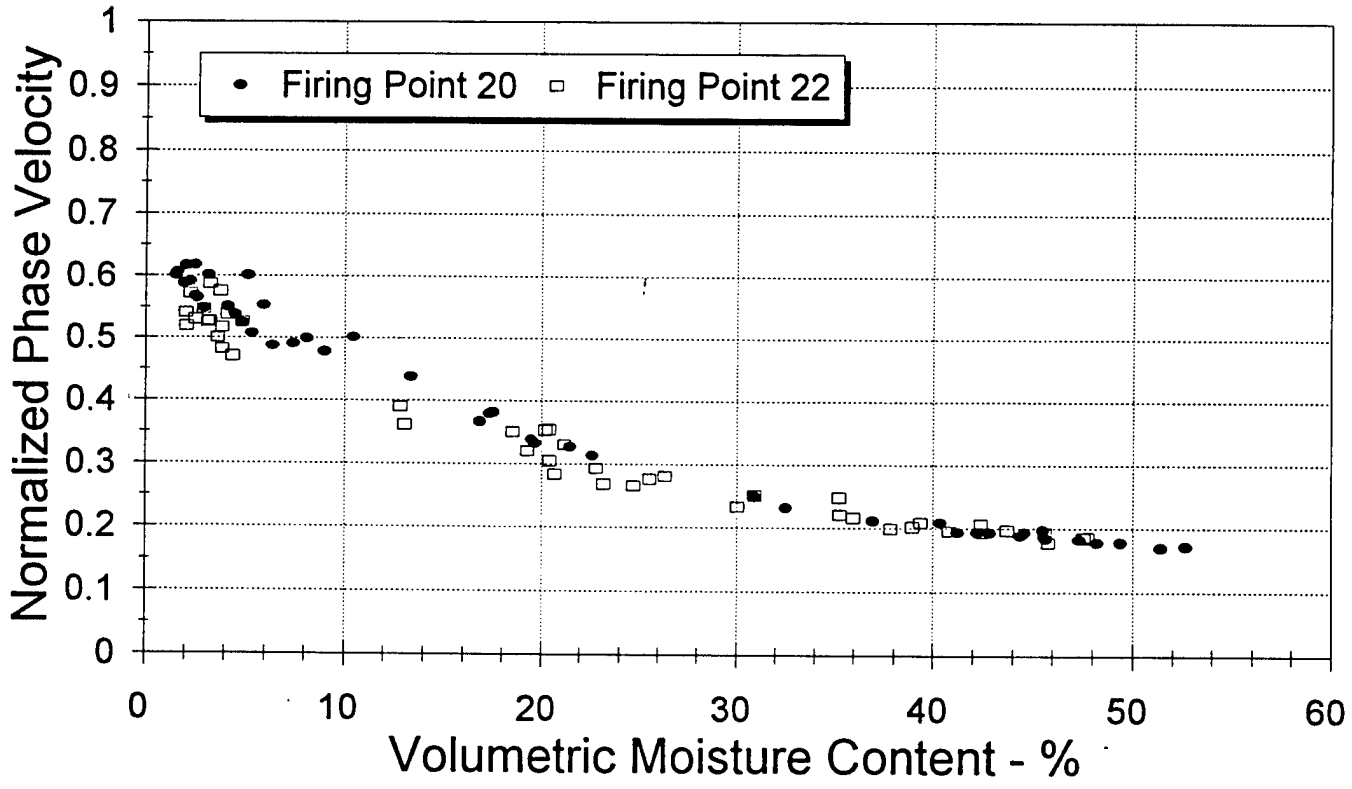

AP Hill_2
Properties at 100 MHz , All Depths
Firing Point 20
Firing Point 22
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

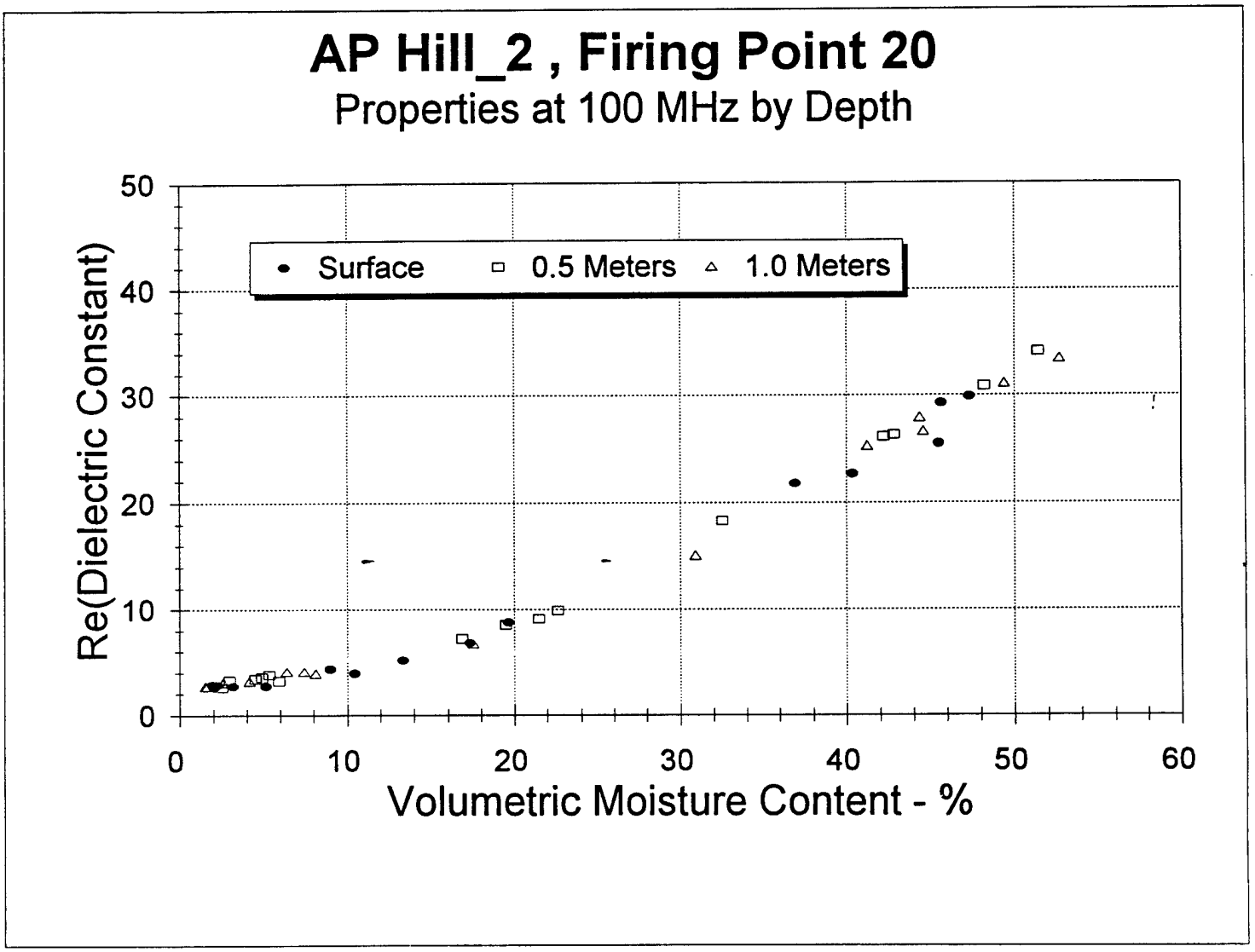

AP Hill_2
Properties at 100 MHz , All Depths
Firing Point 20
Firing Point 22
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

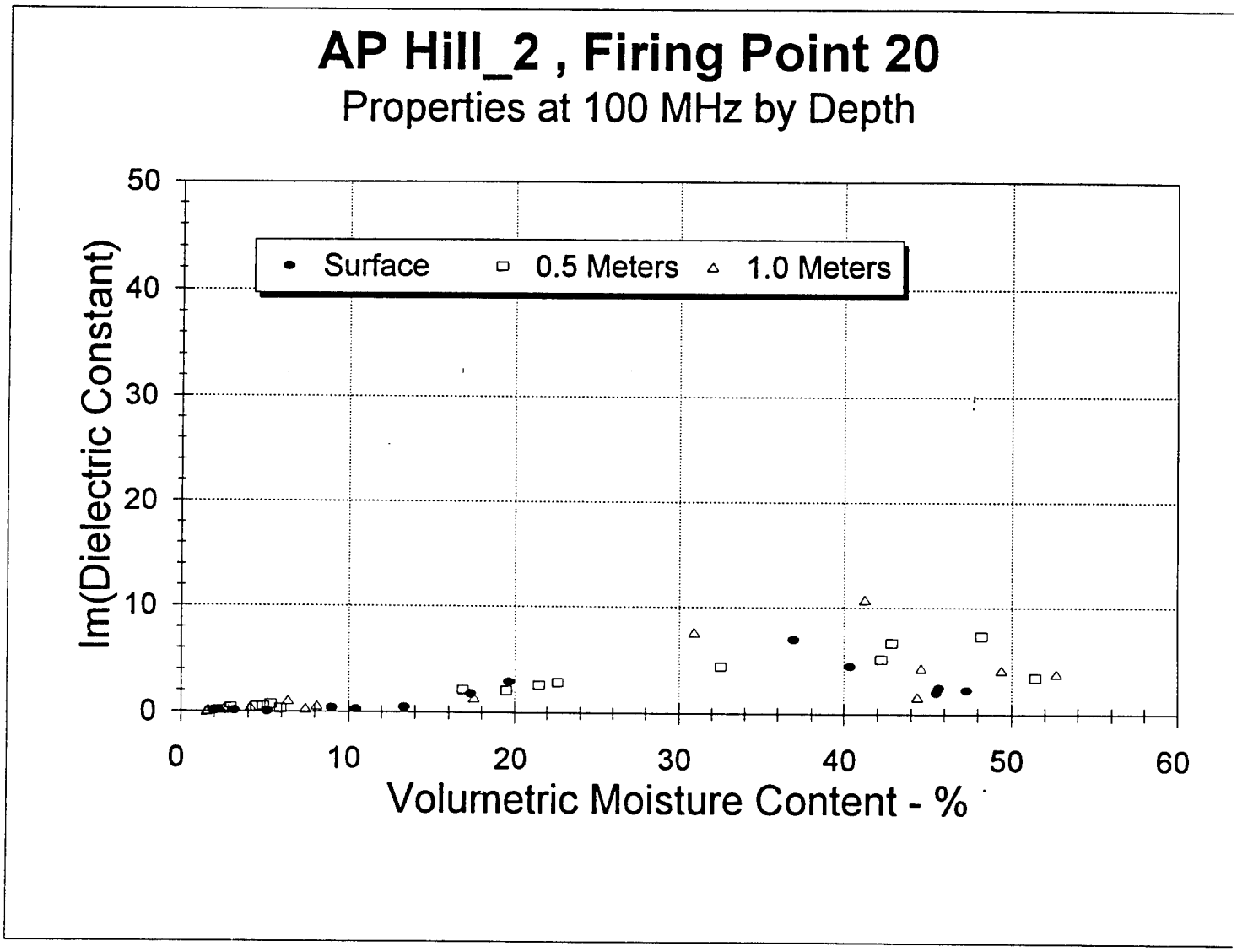

AP Hill_2
Properties at 100 MHz , All Depths
Firing Point 20
Firing Point 22
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
60
Volumetric Moisture Content - %

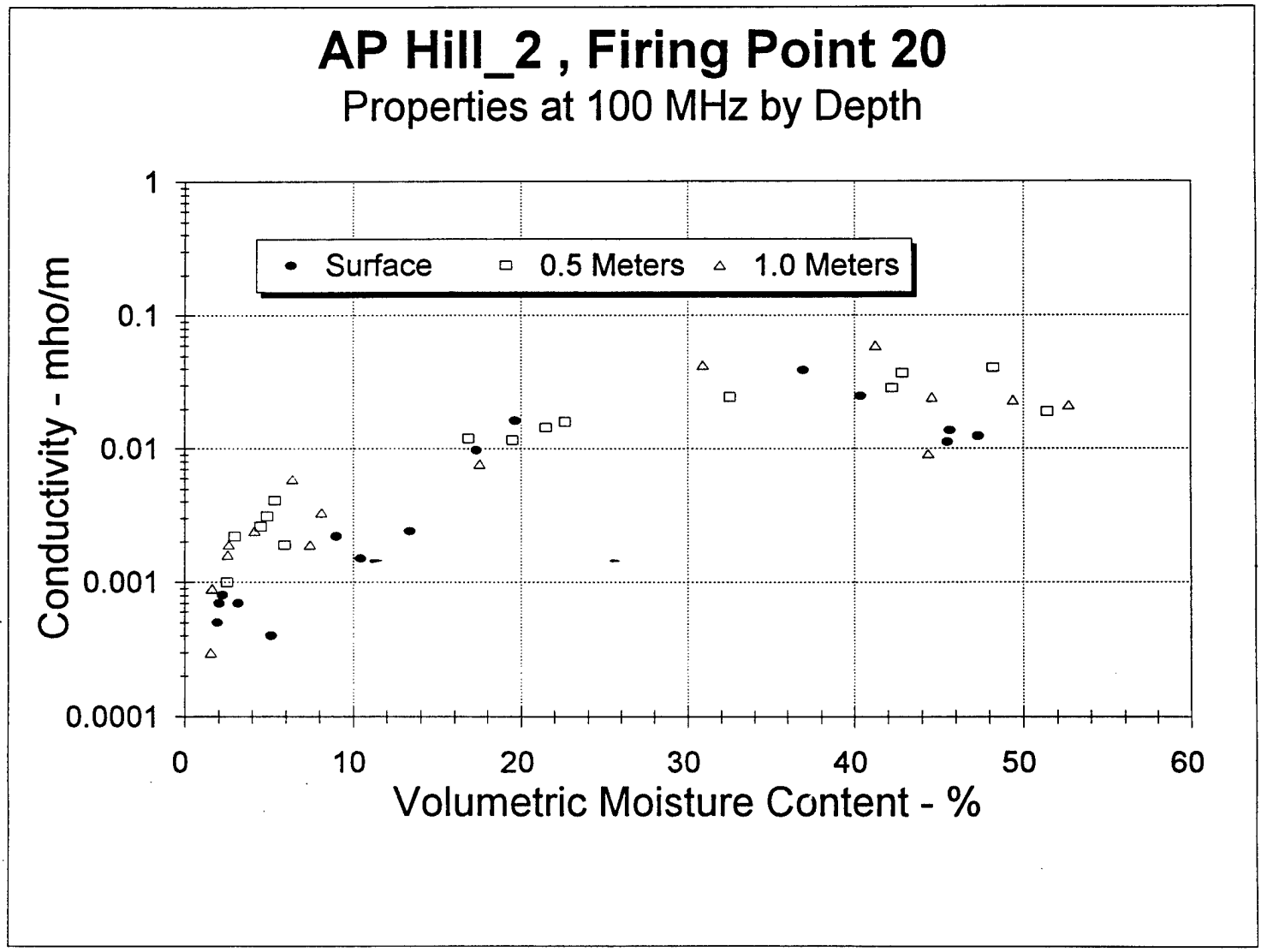
# AP Hill_2

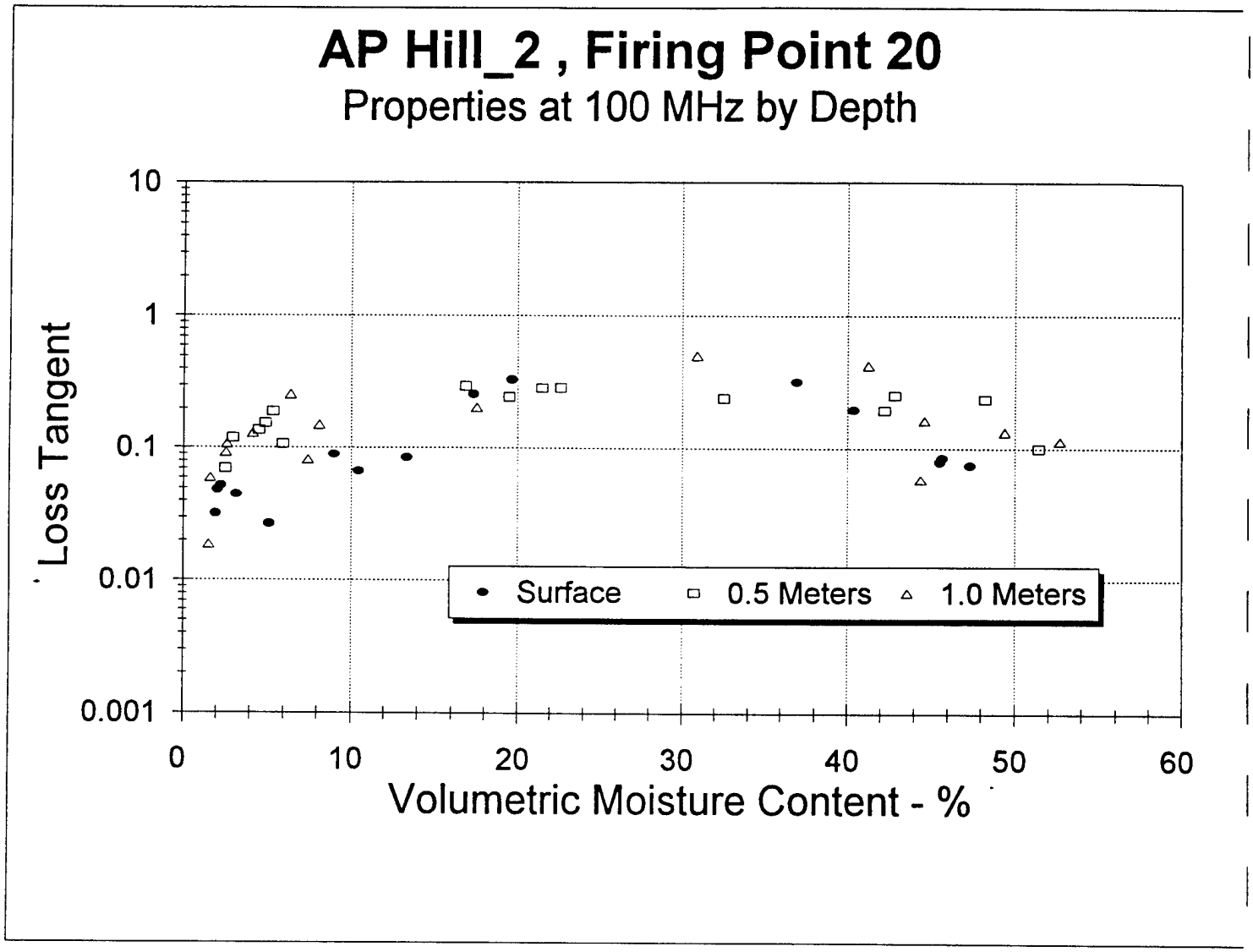
Properties at 100 MHz , All Depths

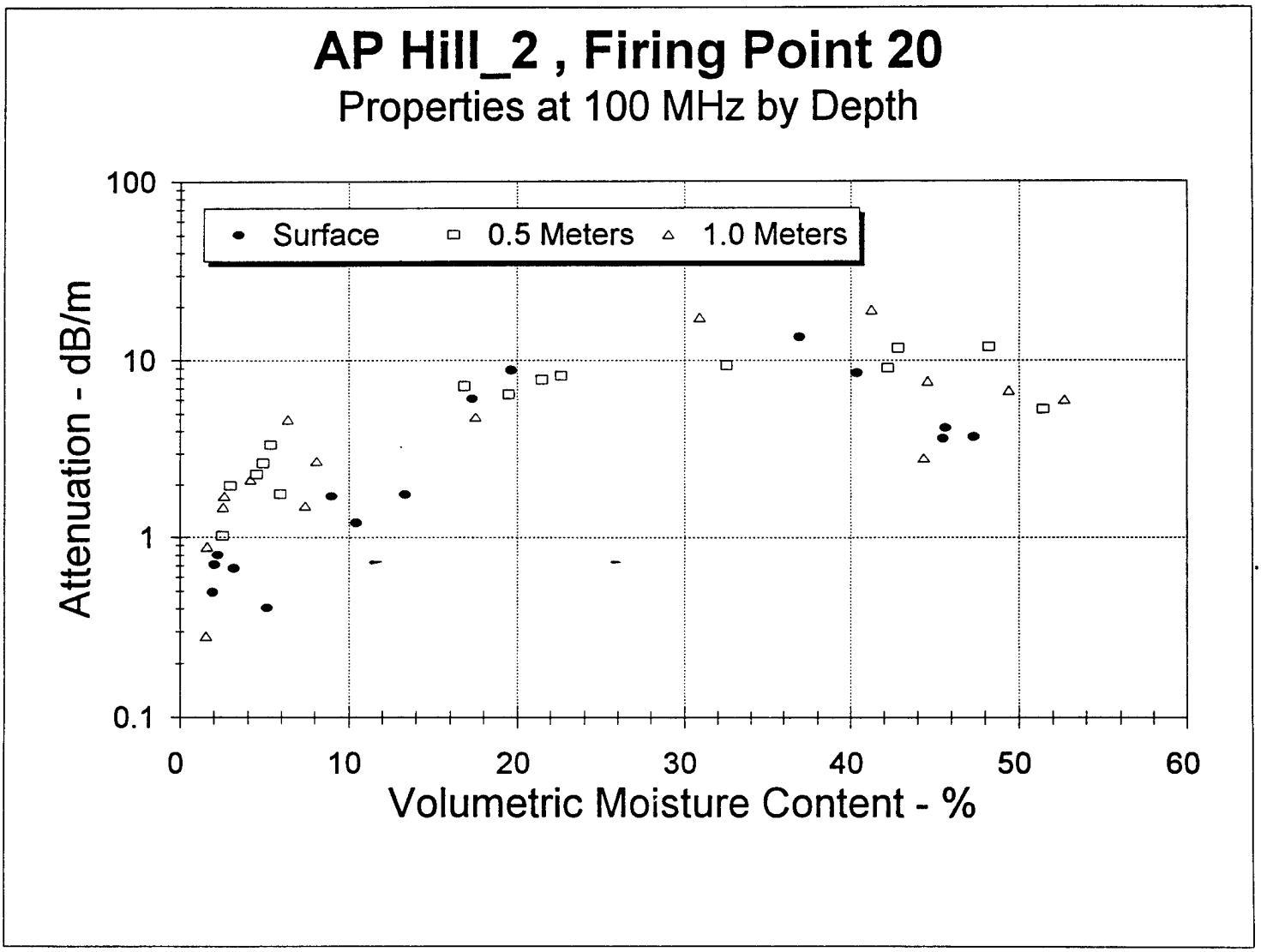



AP Hill_2 , Firing Point 20
Properties at 100 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50
60


AP Hill_2 , Firing Point 20
Properties at 100 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Im(Dielectric Constant)
0
10
20
30
40
50
0
10
20
30
40
50
60
Volumetric Moisture Content - %

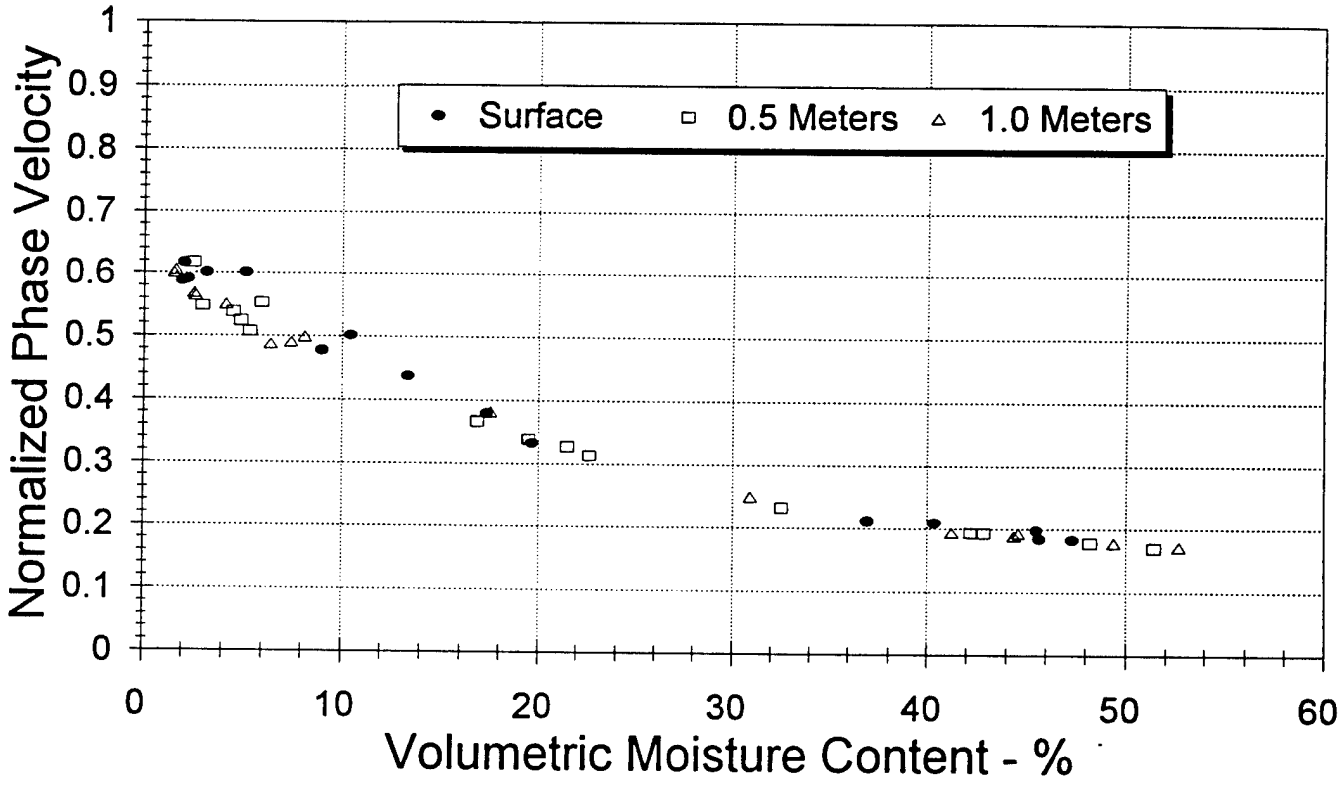

AP Hill_2 , Firing Point 20
Properties at 100 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

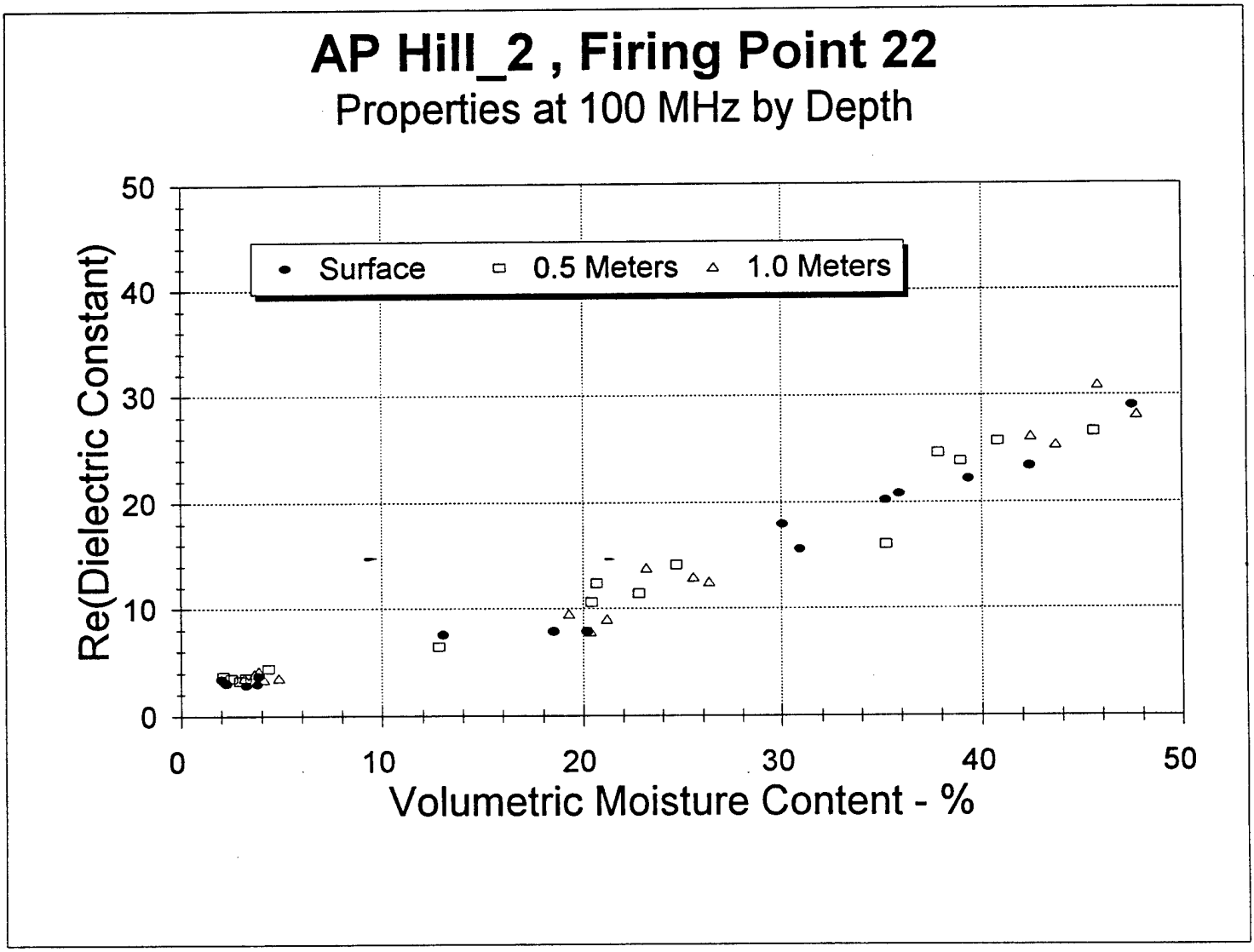

AP Hill_2 , Firing Point 20
Properties at 100 MHz by Depth
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters


AP Hill_2 , Firing Point 20
Properties at 100 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
60
Volumetric Moisture Content - %

# AP Hill_2 , Firing Point 20

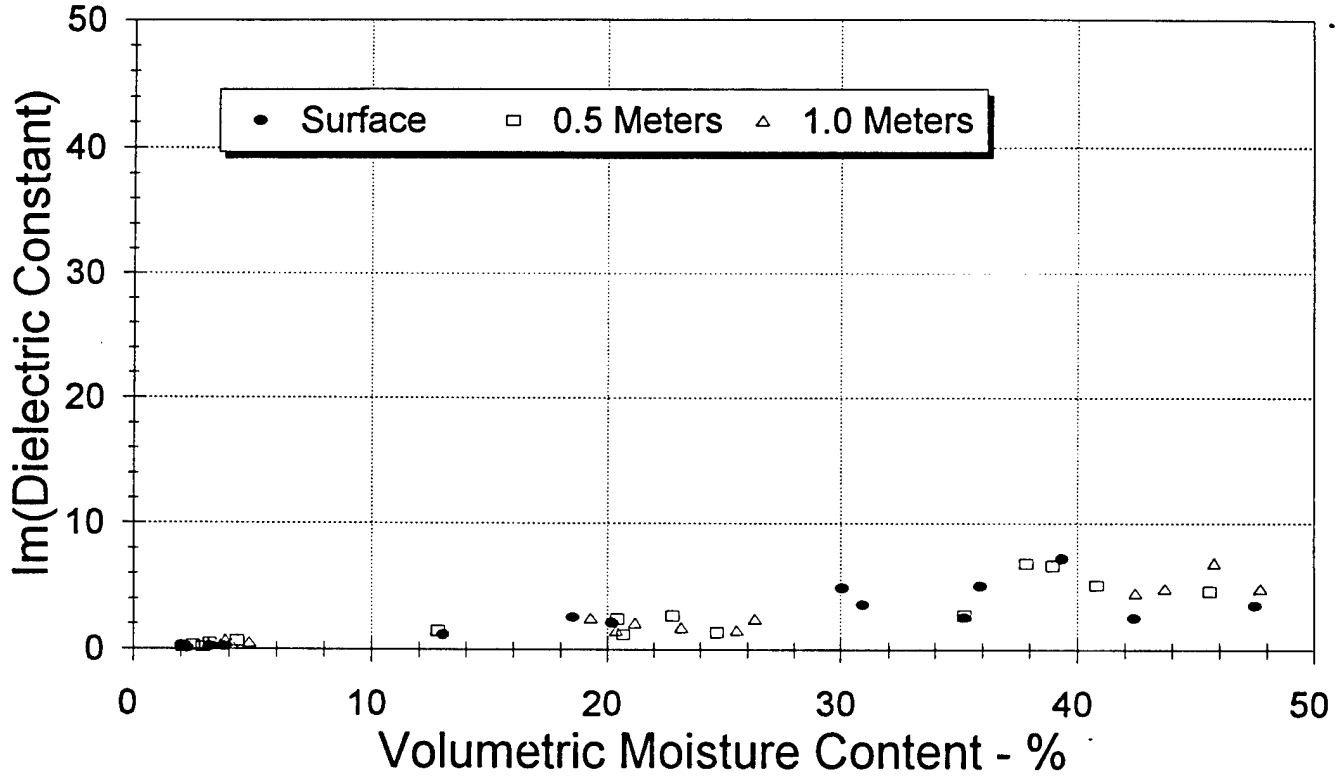
## Properties at 100 MHz by Depth

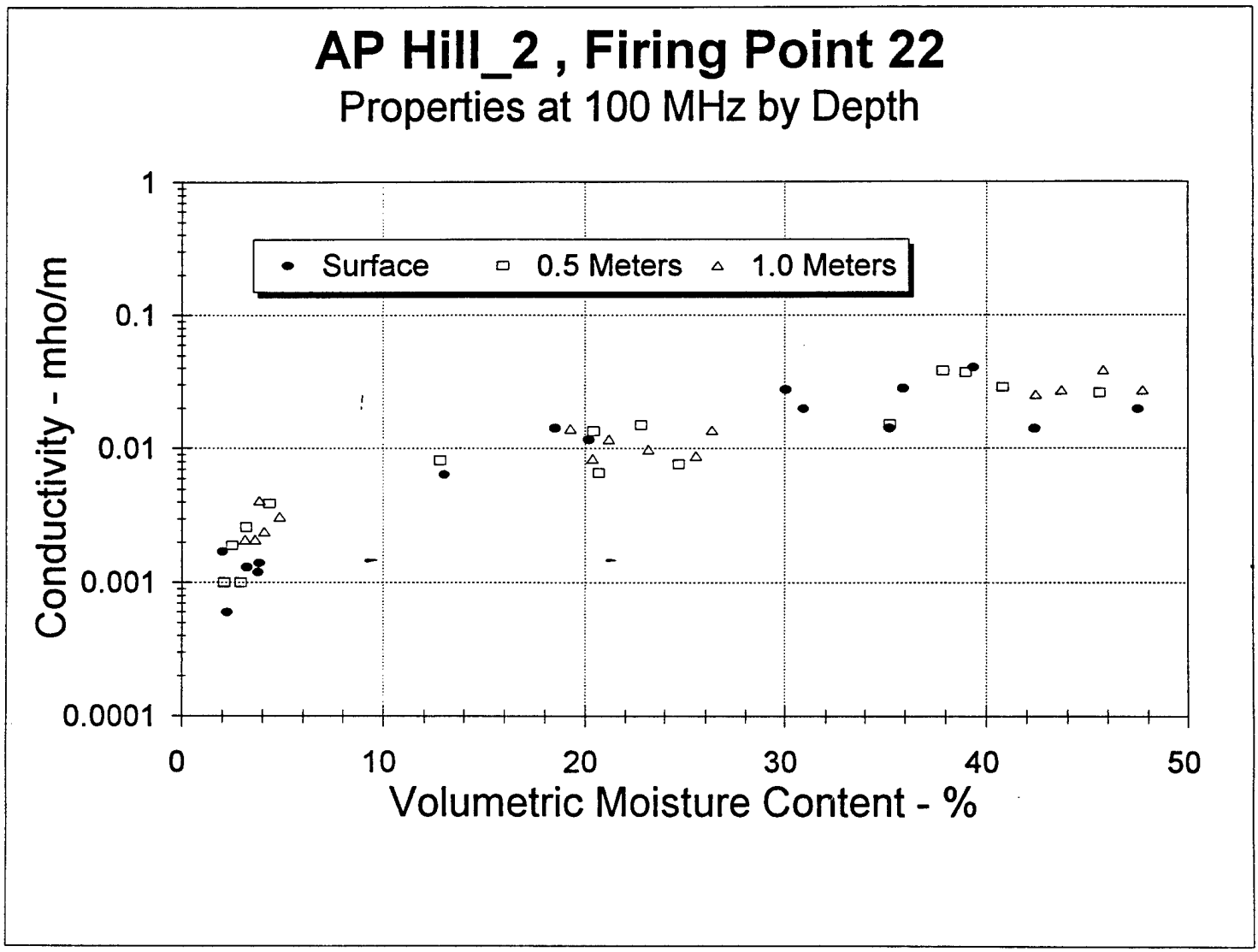


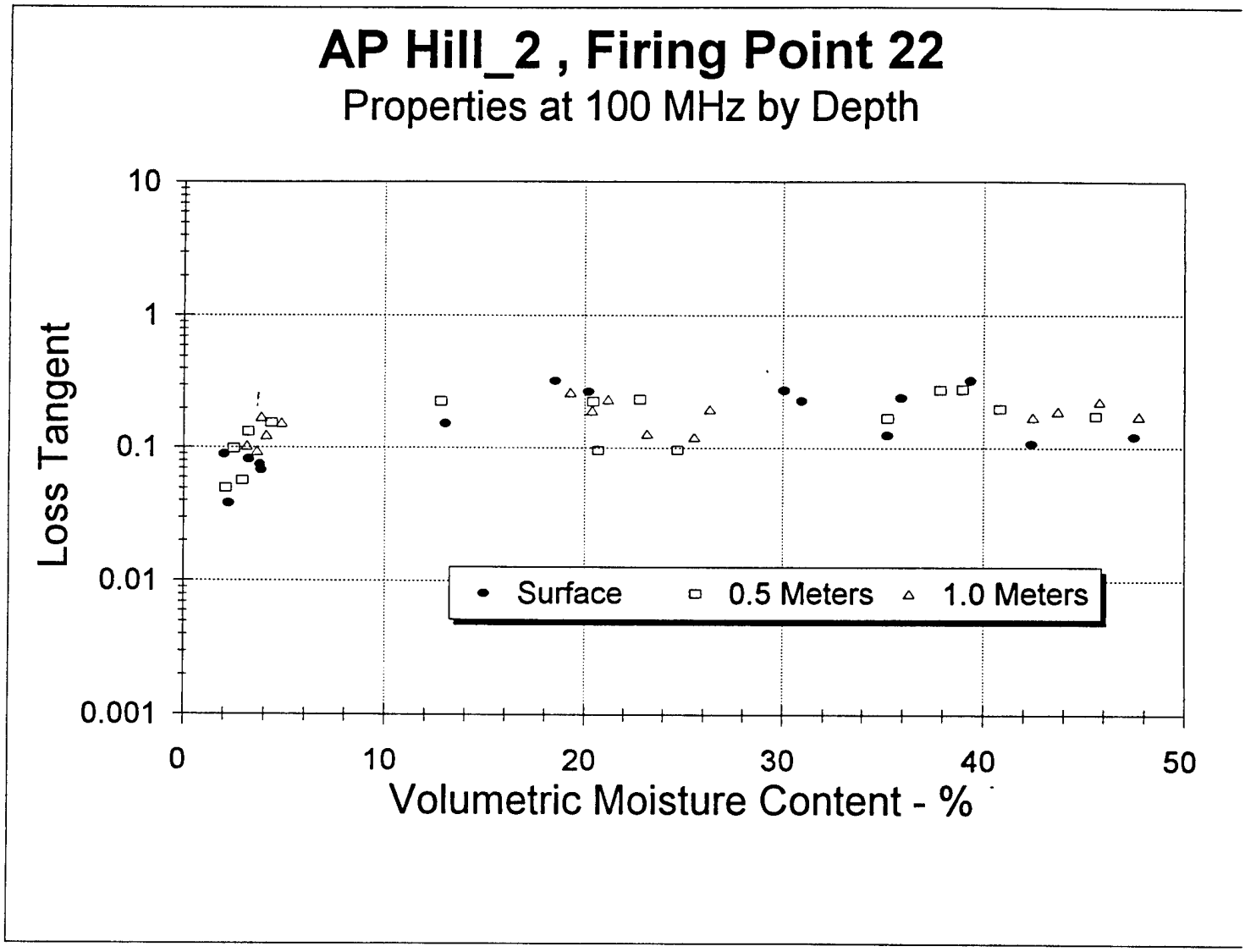

AP Hill_2 , Firing Point 22
Properties at 100 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50

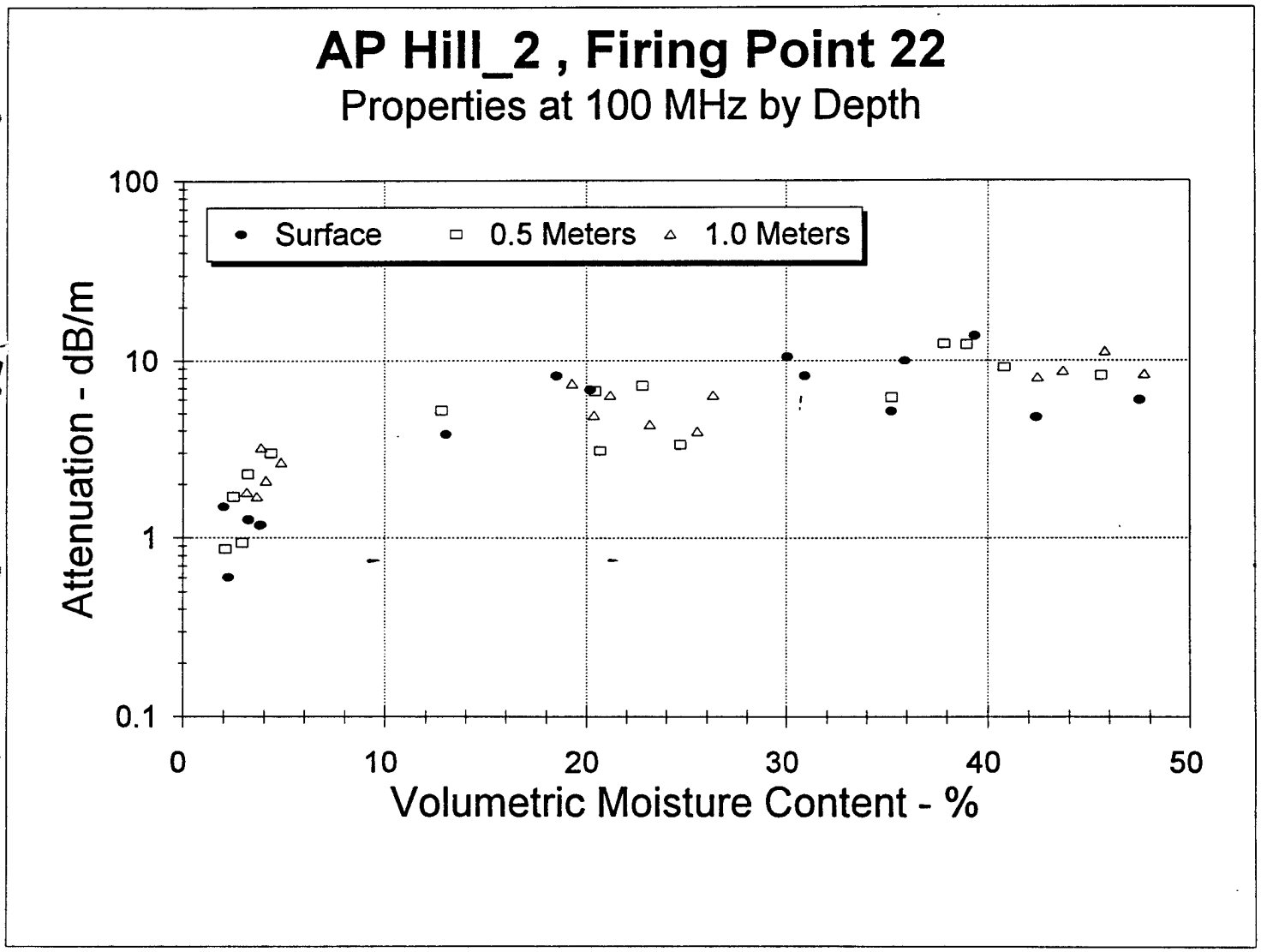
# AP Hill_2 , Firing Point 22

## Properties at 100 MHz by Depth



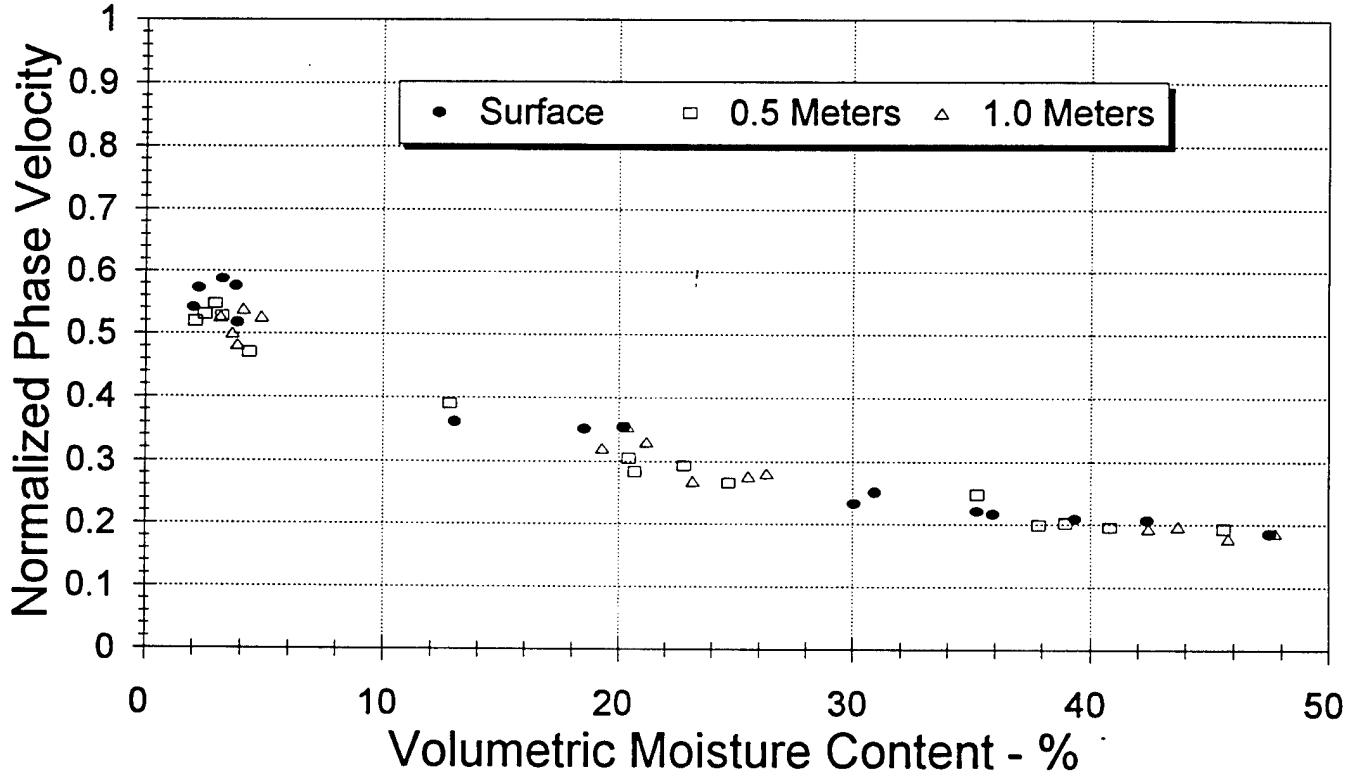

AP Hill_2 , Firing Point 22
Properties at 100 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
Volumetric Moisture Content - %


AP Hill_2 , Firing Point 22
Properties at 100 MHz by Depth
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters


AP Hill_2 , Firing Point 22
Properties at 100 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
Volumetric Moisture Content - %

# AP Hill_2 , Firing Point 22

## Properties at 100 MHz by Depth



Fort A.P. Hill_2
Properties at 200 Mhz

Fort AP Hill_2 Soil Properties at 200 MHz

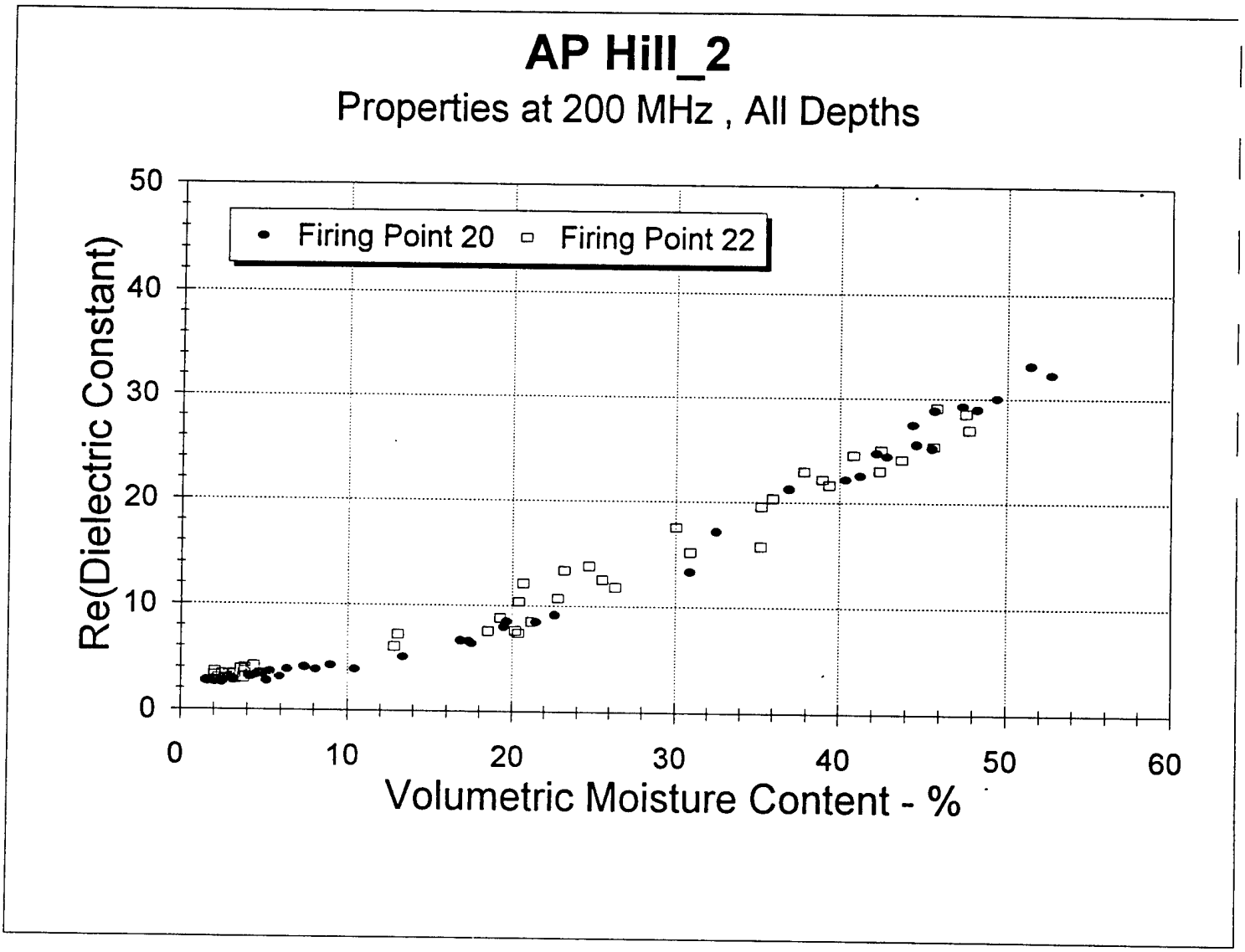
Firing Point 20

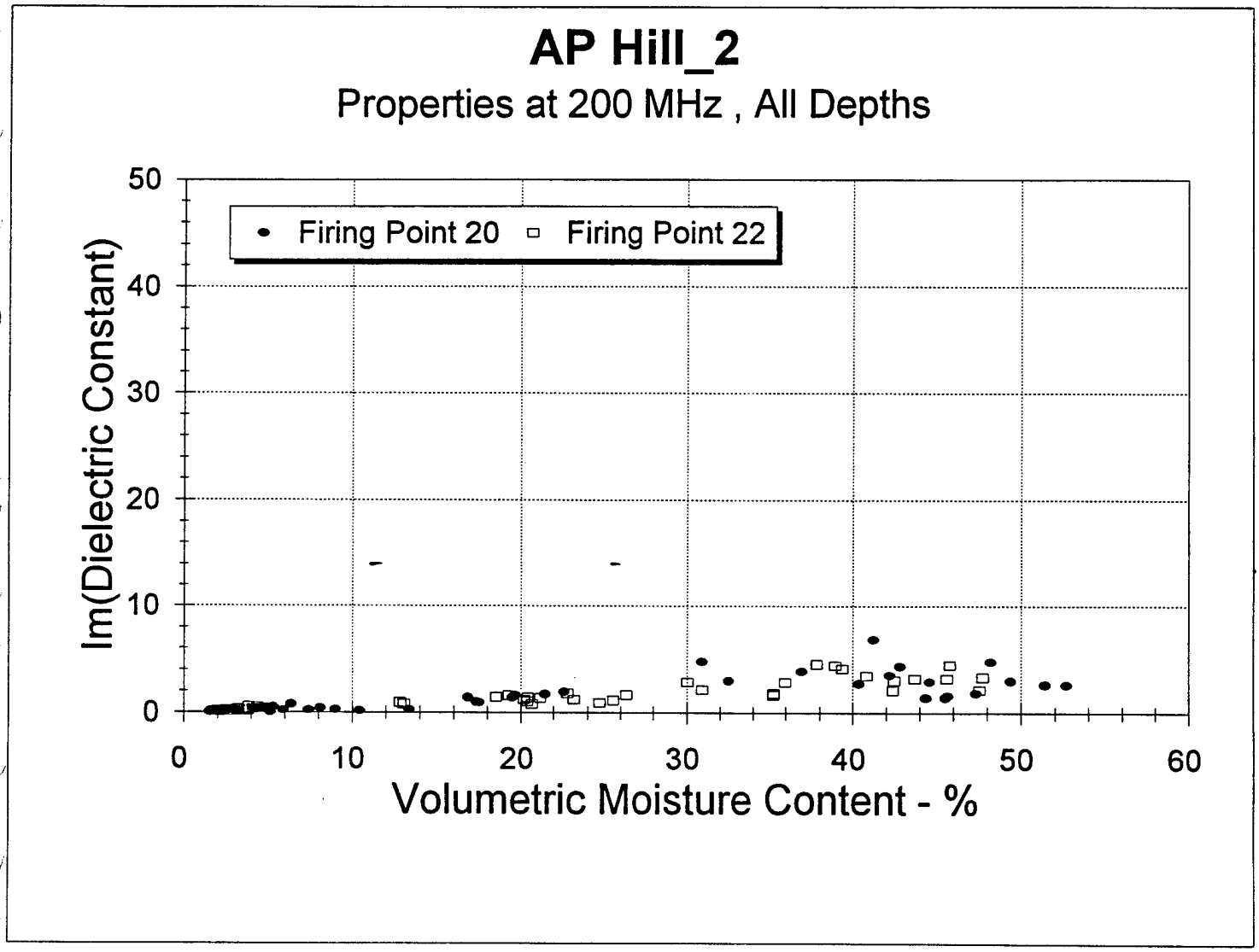
| File Name | Vol Moist | Dry Dens g/cc | Re(eps) | Im(eps) | Cond mho/m | Loss Tan | Attn dB/m | Norm Vel |
|---|---|---|---|---|---|---|---|---|
| 200_1b | 2.57 | 1.40 | 2.96 | 0.24 | 0.003 | 0.08 | 2.49 | 0.58 |
| 200_1d | 2.65 | 1.40 | 3.00 | 0.27 | 0.003 | 0.09 | 2.78 | 0.58 |
| 200_1w | 49.42 | 1.40 | 30.08 | 3.00 | 0.033 | 0.10 | 9.94 | 0.18 |
| 200_2b | 5.97 | 1.21 | 3.13 | 0.24 | 0.003 | 0.08 | 2.48 | 0.56 |
| 200_2d | 2.52 | 1.21 | 2.55 | 0.14 | 0.002 | 0.05 | 1.57 | 0.63 |
| 200_2w | 51.44 | 1.21 | 33.21 | 2.64 | 0.029 | 0.08 | 8.34 | 0.17 |
| 200_sb | 9.01 | 1.39 | 4.24 | 0.29 | 0.003 | 0.07 | 2.53 | 0.49 |
| 200_sd | 2.27 | 1.39 | 2.79 | 0.12 | 0.001 | 0.04 | 1.35 | 0.60 |
| 200_sw | 47.36 | 1.39 | 29.34 | 1.88 | 0.021 | 0.06 | 6.31 | 0.18 |
| 20122_1b | 30.94 | 1.53 | 13.36 | 4.80 | 0.053 | 0.36 | 23.51 | 0.27 |
| 20122_1d | 6.41 | 1.53 | 3.83 | 0.79 | 0.009 | 0.21 | 7.28 | 0.51 |
| 20122_1w | 41.25 | 1.53 | 22.56 | 6.88 | 0.077 | 0.31 | 26.06 | 0.21 |
| 20122_2b | 16.89 | 1.37 | 6.68 | 1.43 | 0.016 | 0.21 | 10.03 | 0.38 |
| 20122_2d | 2.98 | 1.37 | 3.17 | 0.32 | 0.004 | 0.10 | 3.28 | 0.56 |
| 20122_2w | 48.22 | 1.37 | 28.98 | 4.80 | 0.053 | 0.17 | 16.17 | 0.19 |
| 20122_sb | 17.37 | 1.47 | 6.65 | 1.04 | 0.012 | 0.16 | 7.29 | 0.39 |
| 20122_sd | 3.19 | 1.47 | 2.77 | 0.10 | 0.001 | 0.04 | 1.08 | 0.60 |
| 20122_sw | 40.39 | 1.47 | 22.22 | 2.73 | 0.030 | 0.12 | 10.53 | 0.21 |
| 20123_1b | 8.11 | 1.33 | 3.82 | 0.41 | 0.005 | 0.11 | 3.84 | 0.51 |
| 20123_1d | 1.61 | 1.33 | 2.69 | 0.14 | 0.002 | 0.05 | 1.54 | 0.61 |
| 20123_1w | 52.69 | 1.33 | 32.32 | 2.60 | 0.029 | 0.08 | 8.30 | 0.18 |
| 20123_2b | 21.49 | 1.66 | 8.49 | 1.75 | 0.020 | 0.21 | 10.89 | 0.34 |
| 20123_2d | 4.55 | 1.66 | 3.33 | 0.35 | 0.004 | 0.11 | 3.53 | 0.55 |
| 20123_2w | 32.55 | 1.66 | 17.16 | 2.98 | 0.033 | 0.17 | 13.06 | 0.24 |
| 20123_sb | 19.71 | 1.54 | 8.52 | 1.66 | 0.018 | 0.19 | 10.28 | 0.34 |
| 20123_sd | 1.95 | 1.54 | 2.87 | 0.08 | 0.001 | 0.03 | 0.86 | 0.59 |
| 20123_sw | 36.96 | 1.54 | 21.30 | 3.88 | 0.043 | 0.18 | 15.22 | 0.22 |
| 2027_1b | 7.44 | 1.53 | 4.04 | 0.24 | 0.003 | 0.06 | 2.18 | 0.50 |
| 2027_1d | 1.54 | 1.53 | 2.74 | 0.06 | 0.001 | 0.02 | 0.61 | 0.60 |
| 2027_1w | 44.38 | 1.53 | 27.49 | 1.43 | 0.016 | 0.05 | 4.96 | 0.19 |
| 2027_2b | 22.63 | 1.53 | 9.19 | 1.94 | 0.022 | 0.21 | 11.55 | 0.33 |
| 2027_2d | 5.34 | 1.53 | 3.61 | 0.55 | 0.006 | 0.15 | 5.25 | 0.53 |
| 2027_2w | 42.86 | 1.53 | 24.45 | 4.38 | 0.049 | 0.18 | 16.06 | 0.20 |
| 2027_sb | 10.49 | 1.44 | 3.87 | 0.19 | 0.002 | 0.05 | 1.72 | 0.51 |
| 2027_sd | 5.16 | 1.44 | 2.72 | 0.05 | 0.001 | 0.02 | 0.60 | 0.61 |
| 2027_sw | 45.55 | 1.44 | 25.25 | 1.42 | 0.016 | 0.06 | 5.13 | 0.20 |
| 2065_1b | 17.55 | 1.47 | 6.43 | 0.94 | 0.011 | 0.15 | 6.73 | 0.39 |
| 2065_1d | 4.15 | 1.47 | 3.12 | 0.31 | 0.004 | 0.10 | 3.22 | 0.57 |
| 2065_1w | 44.58 | 1.47 | 25.59 | 2.93 | 0.033 | 0.11 | 10.53 | 0.20 |
| 2065_2b | 19.52 | 1.48 | 7.98 | 1.44 | 0.016 | 0.18 | 9.21 | 0.35 |
| 2065_2d | 4.91 | 1.48 | 3.40 | 0.43 | 0.005 | 0.13 | 4.21 | 0.54 |
| 2065_2w | 42.22 | 1.48 | 24.77 | 3.53 | 0.039 | 0.14 | 12.86 | 0.20 |
| 2065_sb | 13.39 | 1.37 | 5.11 | 0.30 | 0.003 | 0.06 | 2.38 | 0.44 |
| 2065_sd | 2.09 | 1.37 | 2.61 | 0.09 | 0.001 | 0.04 | 1.06 | 0.62 |
| 2065_sw | 45.70 | 1.37 | 28.87 | 1.61 | 0.018 | 0.06 | 5.44 | 0.19 |

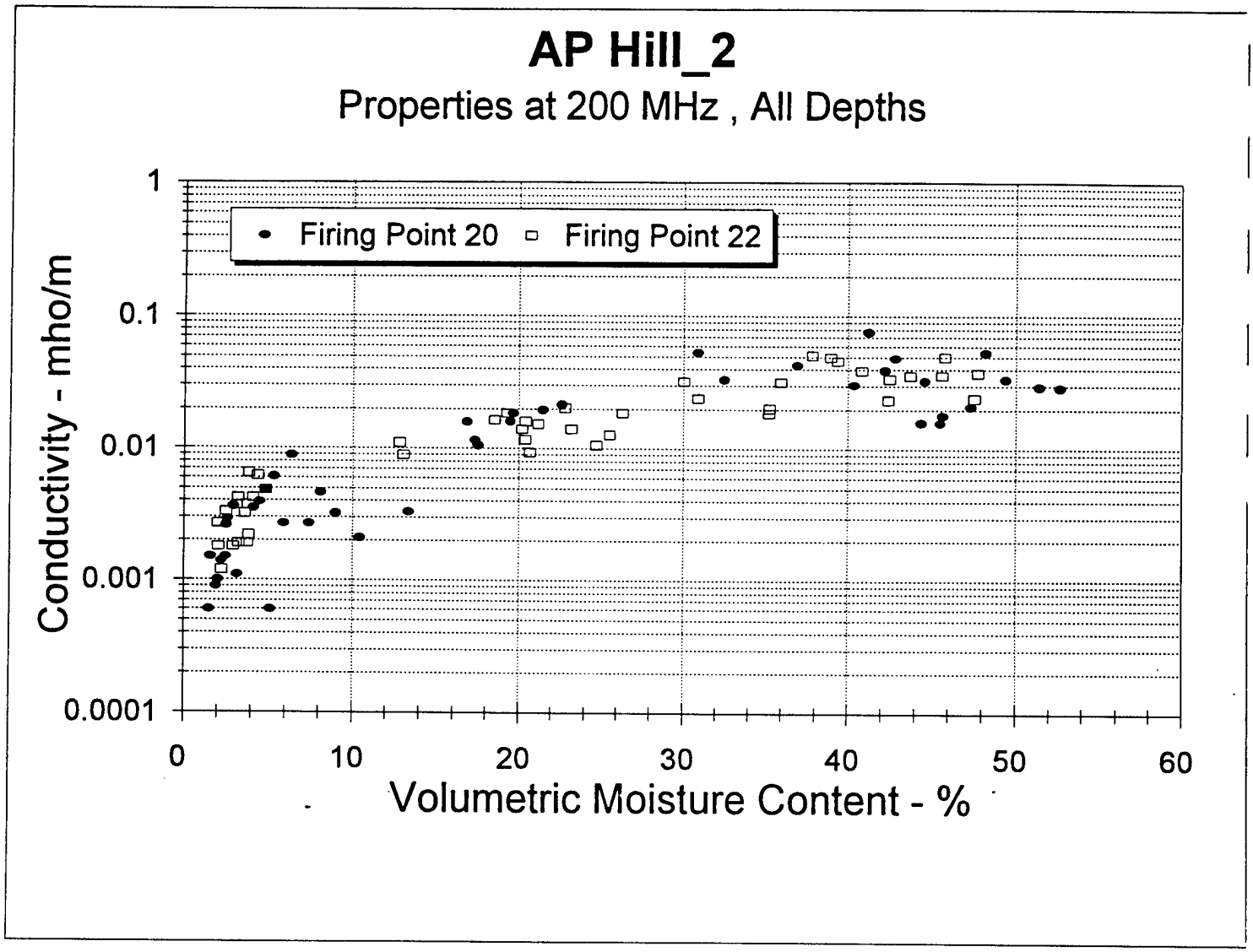
Fort AP Hill_2 Soil Properties at 200 MHz

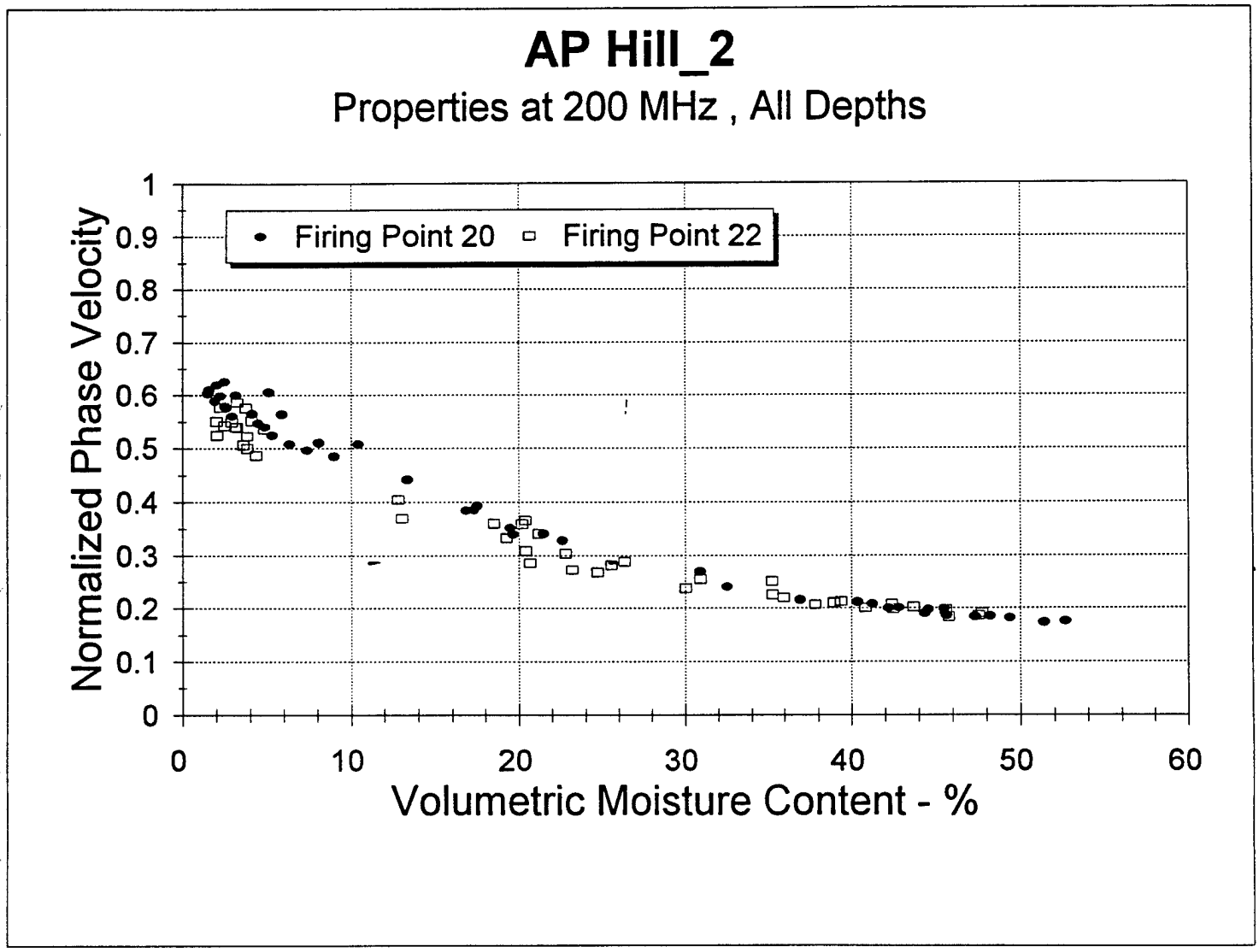
Firing Point 22

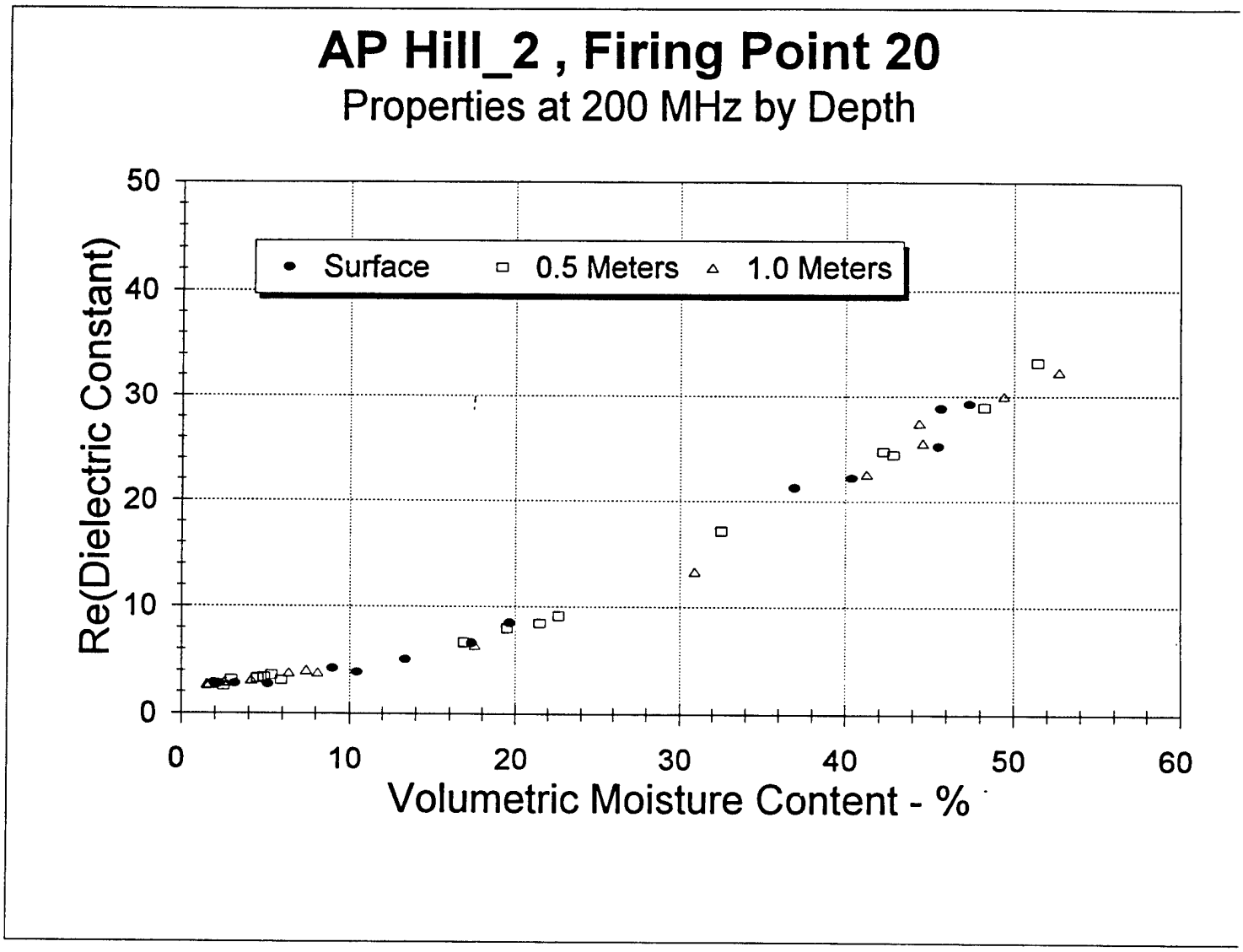
| File Name | Vol Moist | Dry Dens g/cc | Re(eps) | Im(eps) | Cond mho/m | Loss Tan | Attn dB/m | Norm Vel |
|---|---|---|---|---|---|---|---|---|
| 22122_1b | 19.30 | 1.53 | 8.90 | 1.66 | 0.019 | 0.19 | 10.09 | 0.33 |
| 22122_1d | 3.88 | 1.53 | 3.97 | 0.59 | 0.007 | 0.15 | 5.33 | 0.50 |
| 22122_1w | 45.79 | 1.53 | 29.15 | 4.49 | 0.050 | 0.15 | 15.08 | 0.18 |
| 22122_2b | 20.45 | 1.83 | 10.44 | 1.44 | 0.016 | 0.14 | 8.11 | 0.31 |
| 22122_2d | 2.94 | 1.83 | 3.30 | 0.16 | 0.002 | 0.05 | 1.58 | 0.55 |
| 22122_2w | 35.24 | 1.83 | 15.80 | 1.68 | 0.019 | 0.11 | 7.66 | 0.25 |
| 22122_sb | 13.05 | 1.69 | 7.25 | 0.80 | 0.009 | 0.11 | 5.43 | 0.37 |
| 22122_sd | 2.04 | 1.69 | 3.29 | 0.24 | 0.003 | 0.07 | 2.43 | 0.55 |
| 22122_sw | 35.25 | 1.69 | 19.58 | 1.82 | 0.020 | 0.09 | 7.46 | 0.23 |
| 22123_1b | 21.20 | 1.53 | 8.51 | 1.38 | 0.015 | 0.16 | 8.57 | 0.34 |
| 22123_1d | 4.87 | 1.53 | 3.46 | 0.43 | 0.005 | 0.12 | 4.18 | 0.54 |
| 22123_1w | 43.69 | 1.53 | 24.12 | 3.22 | 0.036 | 0.13 | 11.89 | 0.20 |
| 22123_2b | 12.82 | 1.51 | 6.06 | 1.00 | 0.011 | 0.17 | 7.37 | 0.40 |
| 22123_2d | 3.22 | 1.51 | 3.42 | 0.37 | 0.004 | 0.11 | 3.67 | 0.54 |
| 22123_2w | 45.59 | 1.51 | 25.44 | 3.24 | 0.036 | 0.13 | 11.66 | 0.20 |
| 22123_sb | 18.55 | 1.55 | 7.61 | 1.47 | 0.016 | 0.19 | 9.66 | 0.36 |
| 22123_sd | 3.80 | 1.55 | 3.00 | 0.17 | 0.002 | 0.06 | 1.77 | 0.58 |
| 22123_sw | 39.36 | 1.55 | 21.67 | 4.14 | 0.046 | 0.19 | 16.12 | 0.21 |
| 2227_1b | 26.33 | 1.51 | 11.88 | 1.68 | 0.019 | 0.14 | 8.83 | 0.29 |
| 2227_1d | 3.15 | 1.51 | 3.42 | 0.33 | 0.004 | 0.10 | 3.26 | 0.54 |
| 2227_1w | 42.47 | 1.51 | 25.08 | 3.03 | 0.034 | 0.12 | 10.99 | 0.20 |
| 2227_2b | 37.85 | 1.66 | 22.97 | 4.59 | 0.051 | 0.20 | 17.35 | 0.21 |
| 2227_2d | 4.37 | 1.66 | 4.19 | 0.56 | 0.006 | 0.13 | 4.94 | 0.49 |
| 2227_2w | 38.96 | 1.66 | 22.20 | 4.45 | 0.050 | 0.20 | 17.10 | 0.21 |
| 2227_sb | 47.54 | 1.31 | 28.57 | 2.19 | 0.024 | 0.08 | 7.43 | 0.19 |
| 2227_sd | 2.27 | 1.31 | 3.00 | 0.11 | 0.001 | 0.04 | 1.17 | 0.58 |
| 2227_sw | 42.39 | 1.31 | 23.05 | 2.12 | 0.024 | 0.09 | 8.01 | 0.21 |
| 222_1b | 20.41 | 1.40 | 7.43 | 1.06 | 0.012 | 0.14 | 7.03 | 0.37 |
| 222_1d | 4.12 | 1.40 | 3.27 | 0.38 | 0.004 | 0.12 | 3.79 | 0.55 |
| 222_1w | 47.74 | 1.40 | 27.01 | 3.37 | 0.037 | 0.12 | 11.76 | 0.19 |
| 222_2b | 22.82 | 1.57 | 10.77 | 1.81 | 0.020 | 0.17 | 10.01 | 0.30 |
| 222_2d | 2.51 | 1.57 | 3.38 | 0.30 | 0.003 | 0.09 | 2.96 | 0.54 |
| 222_2w | 40.82 | 1.57 | 24.56 | 3.50 | 0.039 | 0.14 | 12.82 | 0.20 |
| 222_sb | 20.23 | 1.55 | 7.65 | 1.26 | 0.014 | 0.16 | 8.24 | 0.36 |
| 222_sd | 3.26 | 1.55 | 2.89 | 0.17 | 0.002 | 0.06 | 1.79 | 0.59 |
| 222_sw | 35.92 | 1.55 | 20.38 | 2.87 | 0.032 | 0.14 | 11.55 | 0.22 |
| 2265_1b | 23.21 | 1.99 | 13.39 | 1.27 | 0.014 | 0.09 | 6.29 | 0.27 |
| 2265_1d | 3.65 | 1.99 | 3.89 | 0.29 | 0.003 | 0.07 | 2.65 | 0.51 |
| 2265_1w | 25.57 | 1.99 | 12.59 | 1.14 | 0.013 | 0.09 | 5.86 | 0.28 |
| 2265_2b | 20.71 | 1.94 | 12.17 | 0.83 | 0.009 | 0.07 | 4.33 | 0.29 |
| 2265_2d | 2.09 | 1.94 | 3.62 | 0.16 | 0.002 | 0.04 | 1.51 | 0.53 |
| 2265_2w | 24.72 | 1.94 | 13.85 | 0.95 | 0.011 | 0.07 | 4.66 | 0.27 |
| 2265_sb | 30.08 | 1.82 | 17.56 | 2.89 | 0.032 | 0.16 | 12.51 | 0.24 |
| 2265_sd | 3.87 | 1.82 | 3.66 | 0.19 | 0.002 | 0.05 | 1.85 | 0.52 |
| 2265_sw | 30.94 | 1.82 | 15.21 | 2.16 | 0.024 | 0.14 | 10.04 | 0.26 |

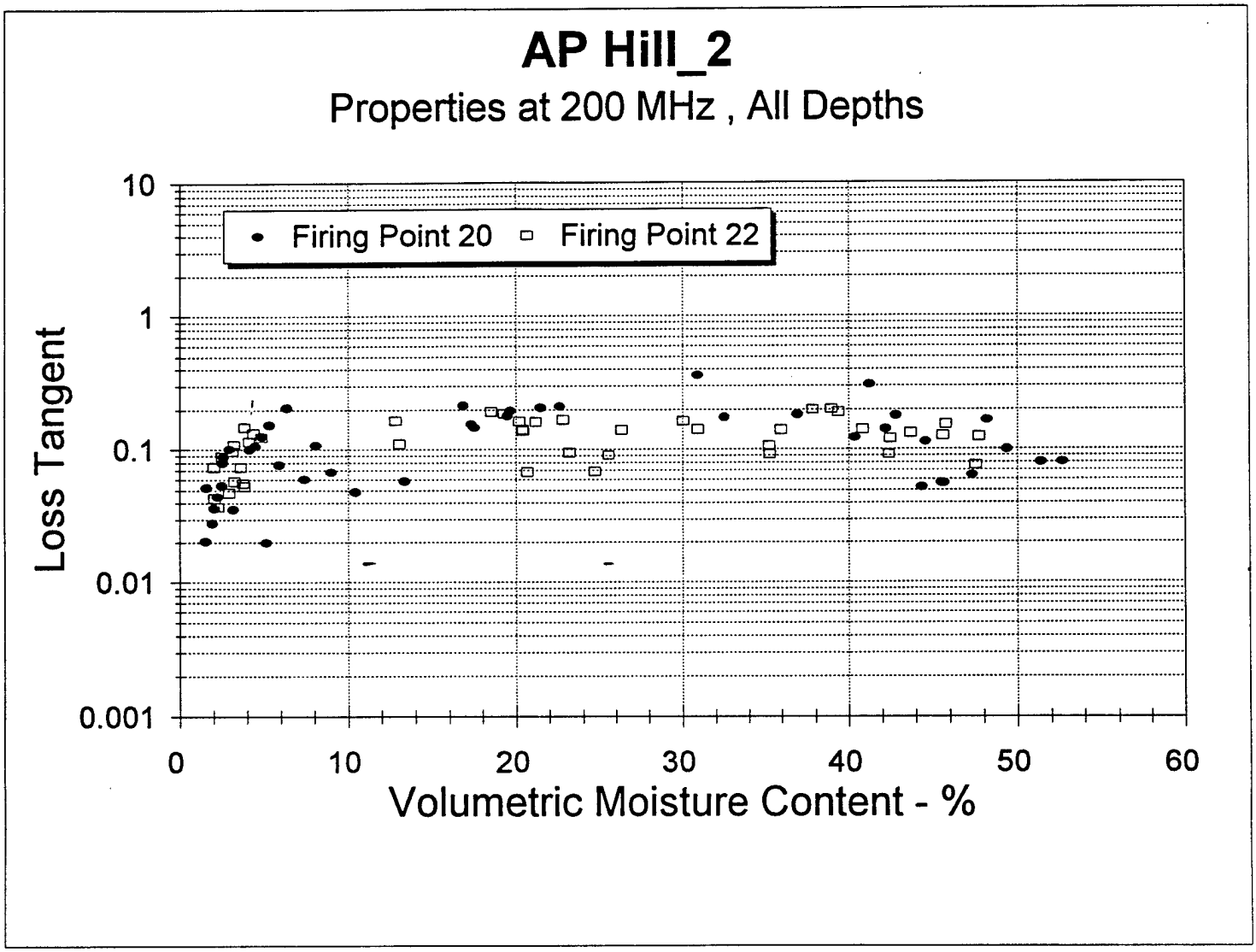

AP Hill_2
Properties at 200 MHz , All Depths
Firing Point 20
Firing Point 22
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50
60


AP Hill_2
Properties at 200 MHz , All Depths
Firing Point 20
Firing Point 22
Im(Dielectric Constant)
0
10
20
30
40
50
0
10
20
30
40
50
60
Volumetric Moisture Content - %


AP Hill_2
Properties at 200 MHz , All Depths
Firing Point 20
Firing Point 22
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

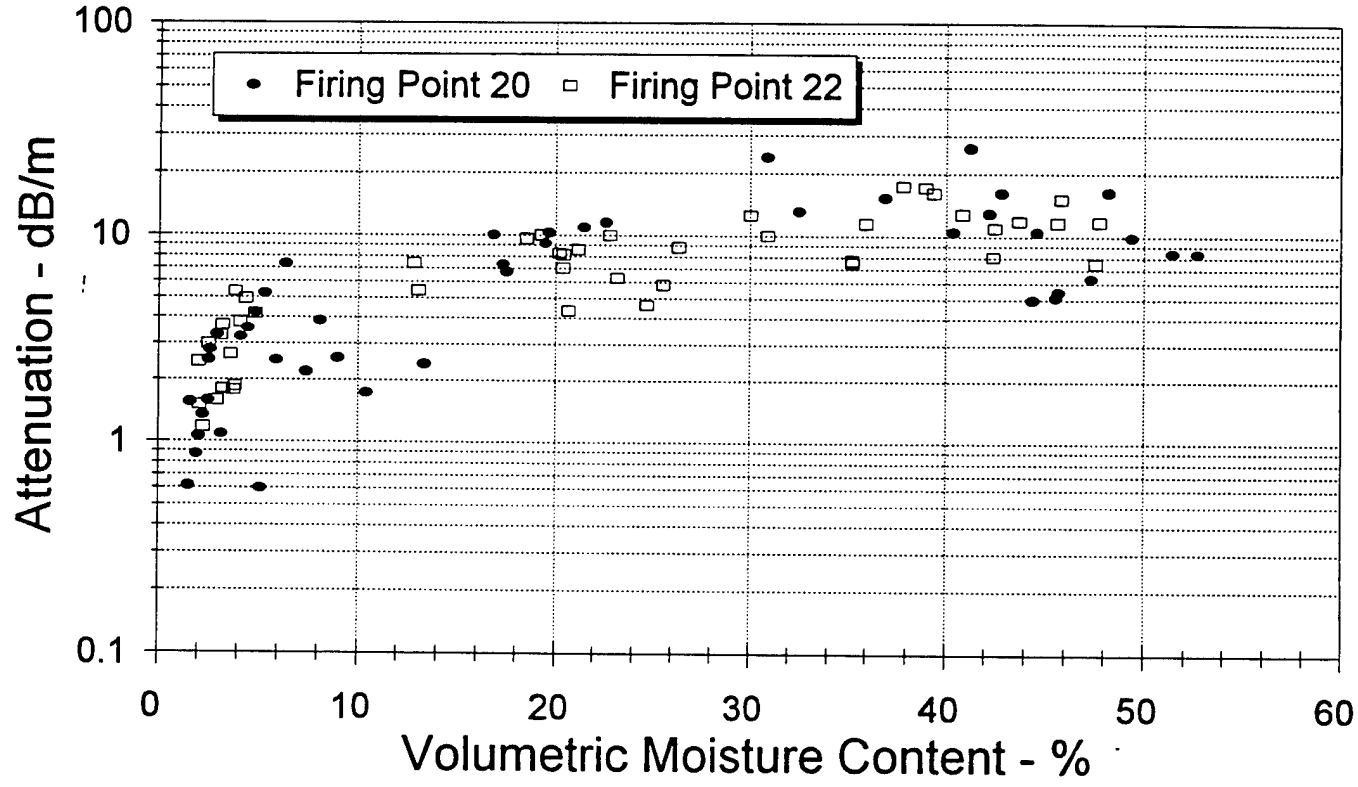

AP Hill_2
Properties at 200 MHz , All Depths
Normalized Phase Velocity
Volumetric Moisture Content - %
Firing Point 20
Firing Point 22
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
50
60

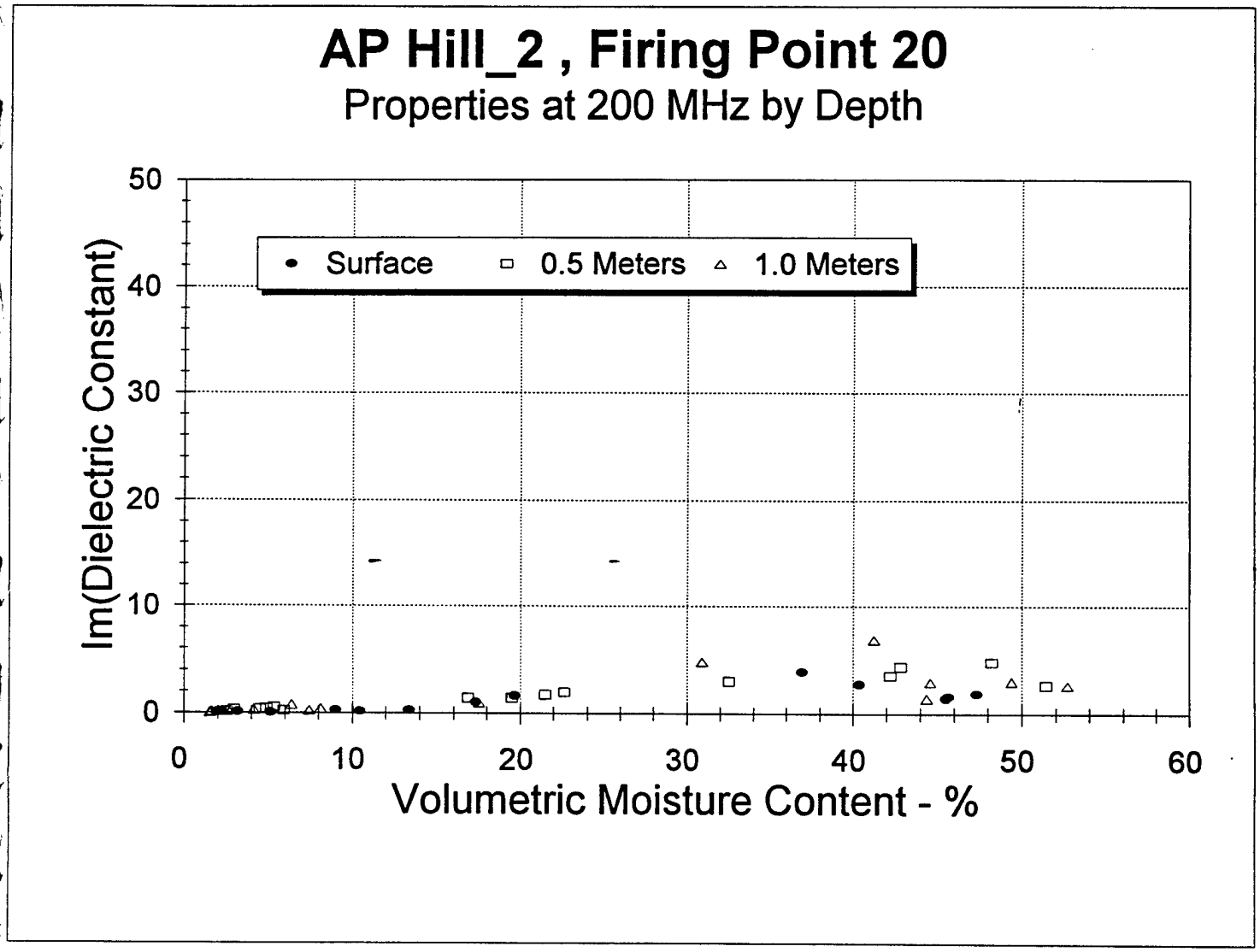

AP Hill_2 , Firing Point 20
Properties at 200 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Re(Dielectric Constant)
0
10
20
30
40
50
0
10
20
30
40
50
60
Volumetric Moisture Content - %

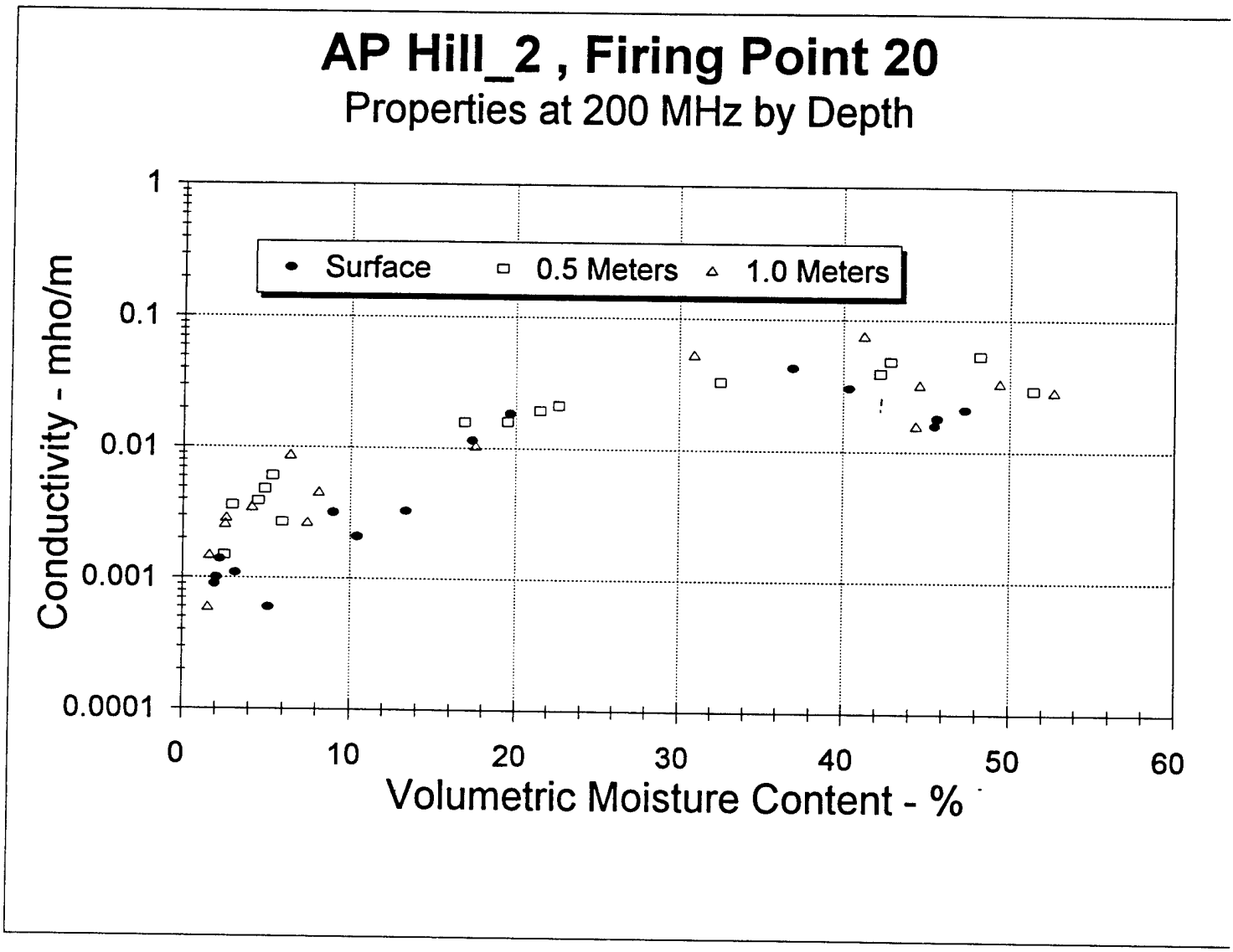

AP Hill_2
Properties at 200 MHz , All Depths
Firing Point 20
Firing Point 22
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

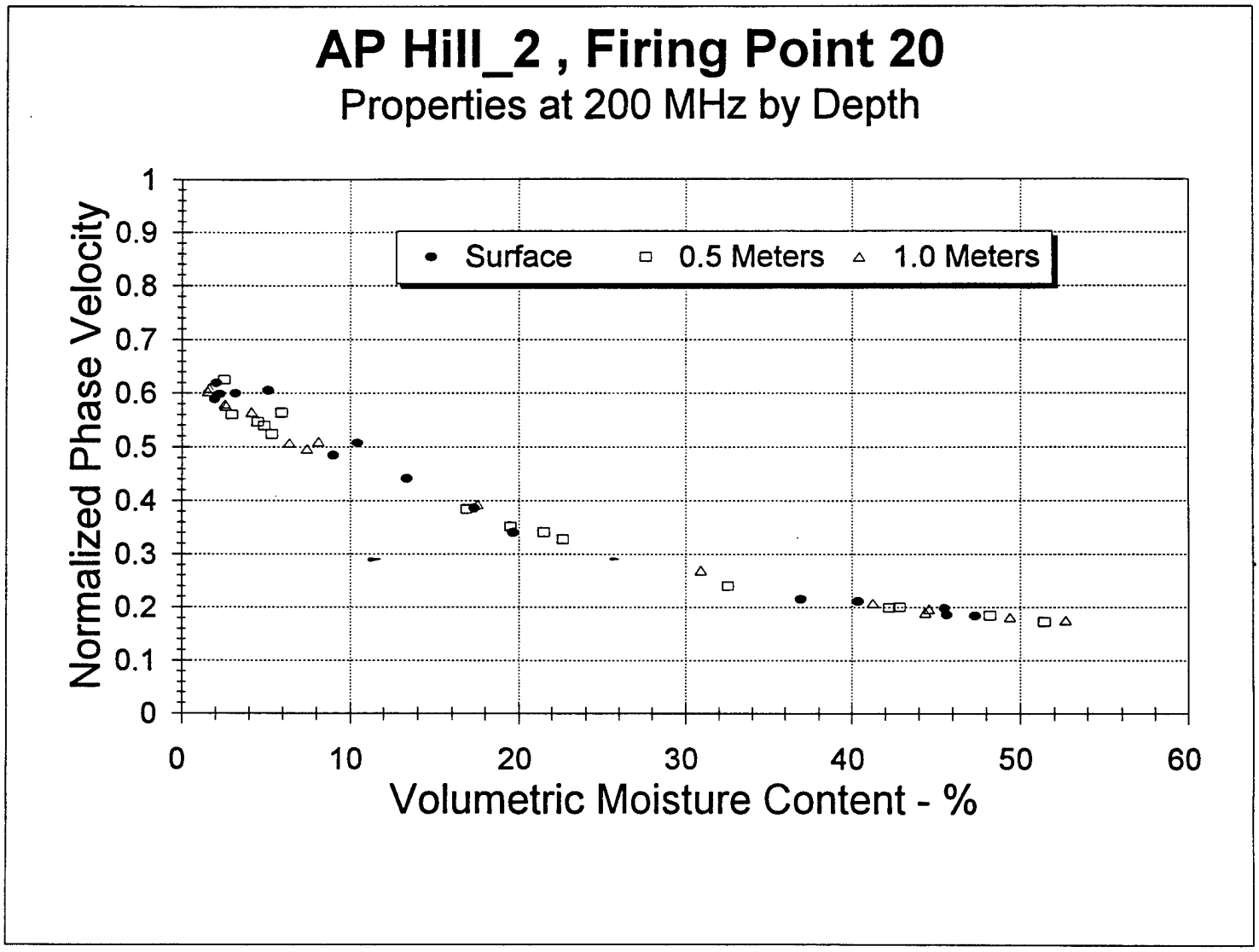
# AP Hill_2

## Properties at 200 MHz , All Depths



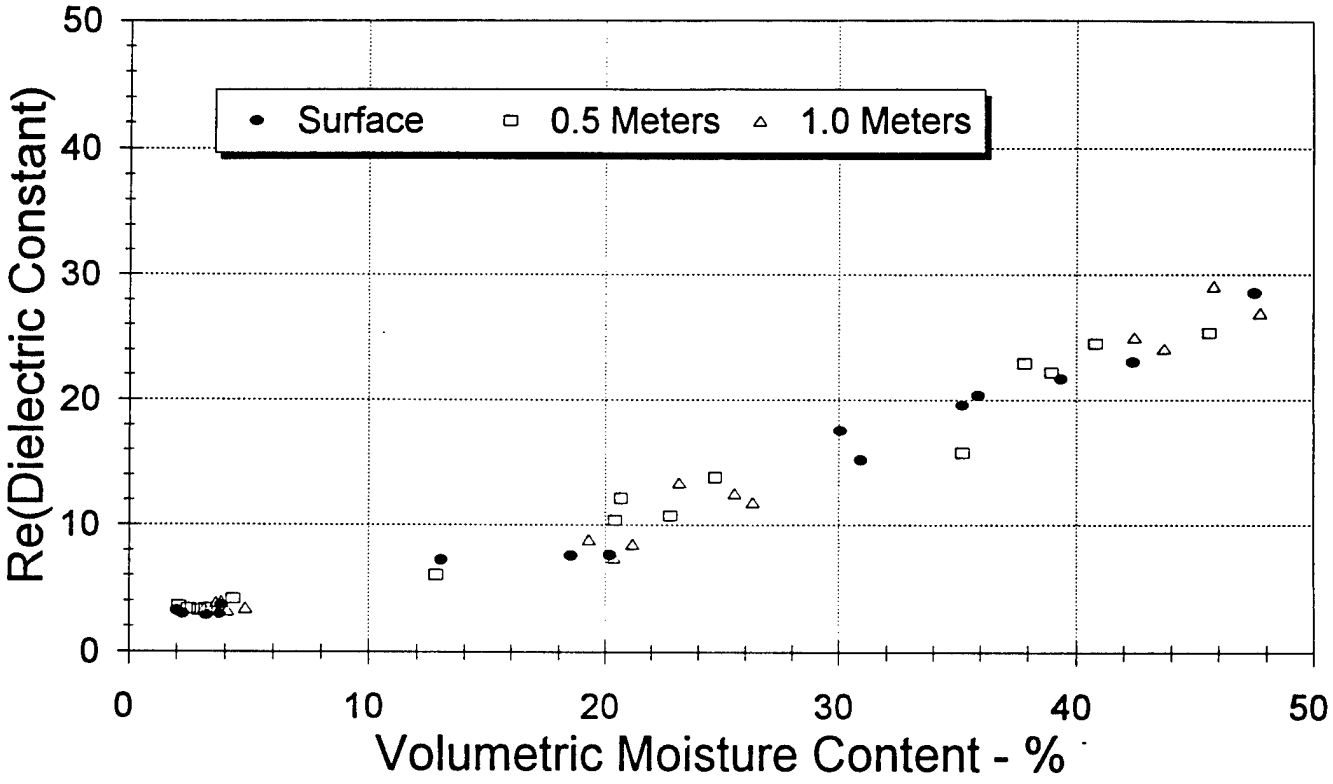

AP Hill_2 , Firing Point 20
Properties at 200 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Im(Dielectric Constant)
0
10
20
30
40
50
0
10
20
30
40
50
60
Volumetric Moisture Content - %

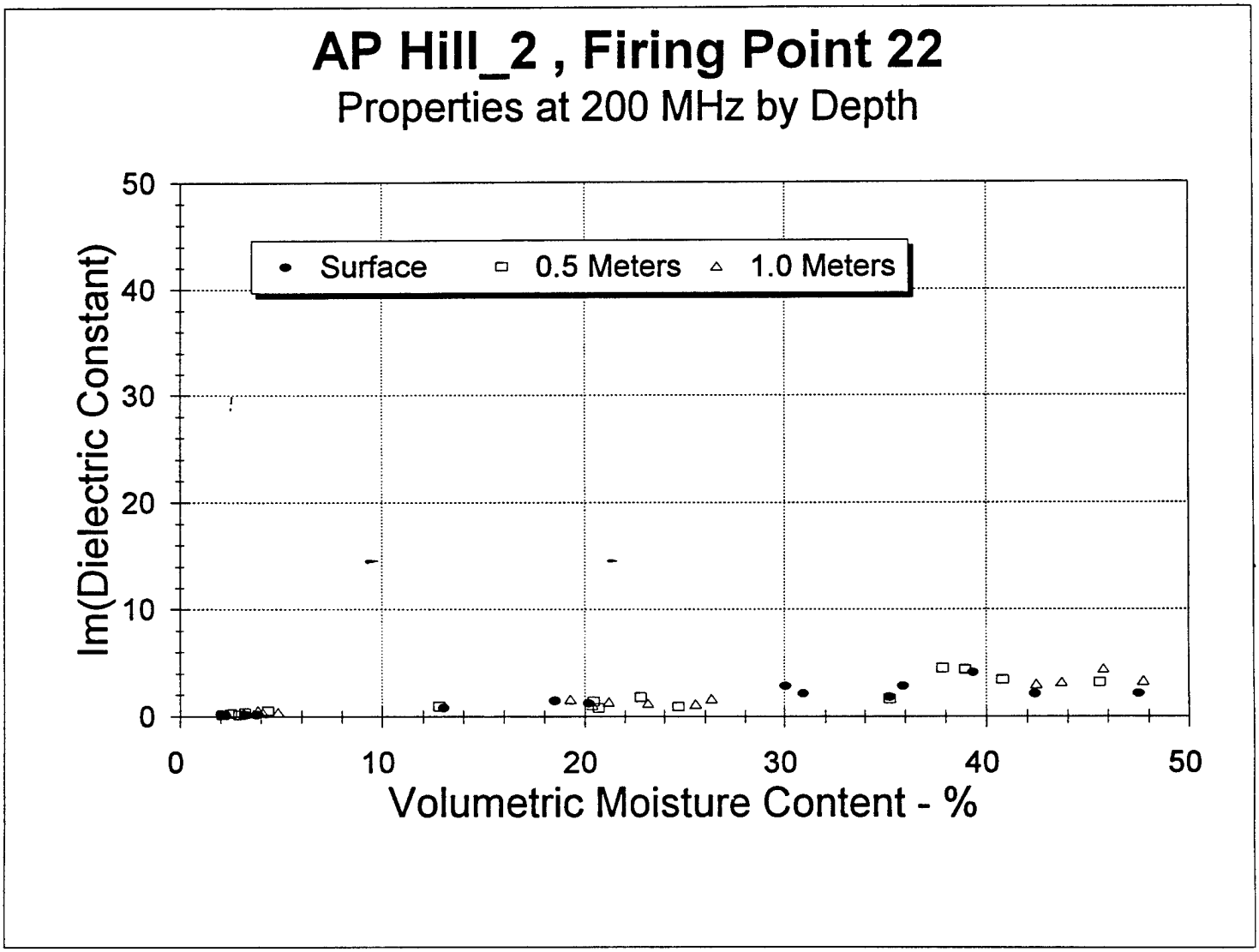

AP Hill_2 , Firing Point 20
Properties at 200 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
Volumetric Moisture Content - %


AP Hill_2 , Firing Point 20
Properties at 200 MHz by Depth
Normalized Phase Velocity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Surface
0.5 Meters
1.0 Meters
0
10
20
30
40
50
60
Volumetric Moisture Content - %

# AP Hill_2 , Firing Point 22

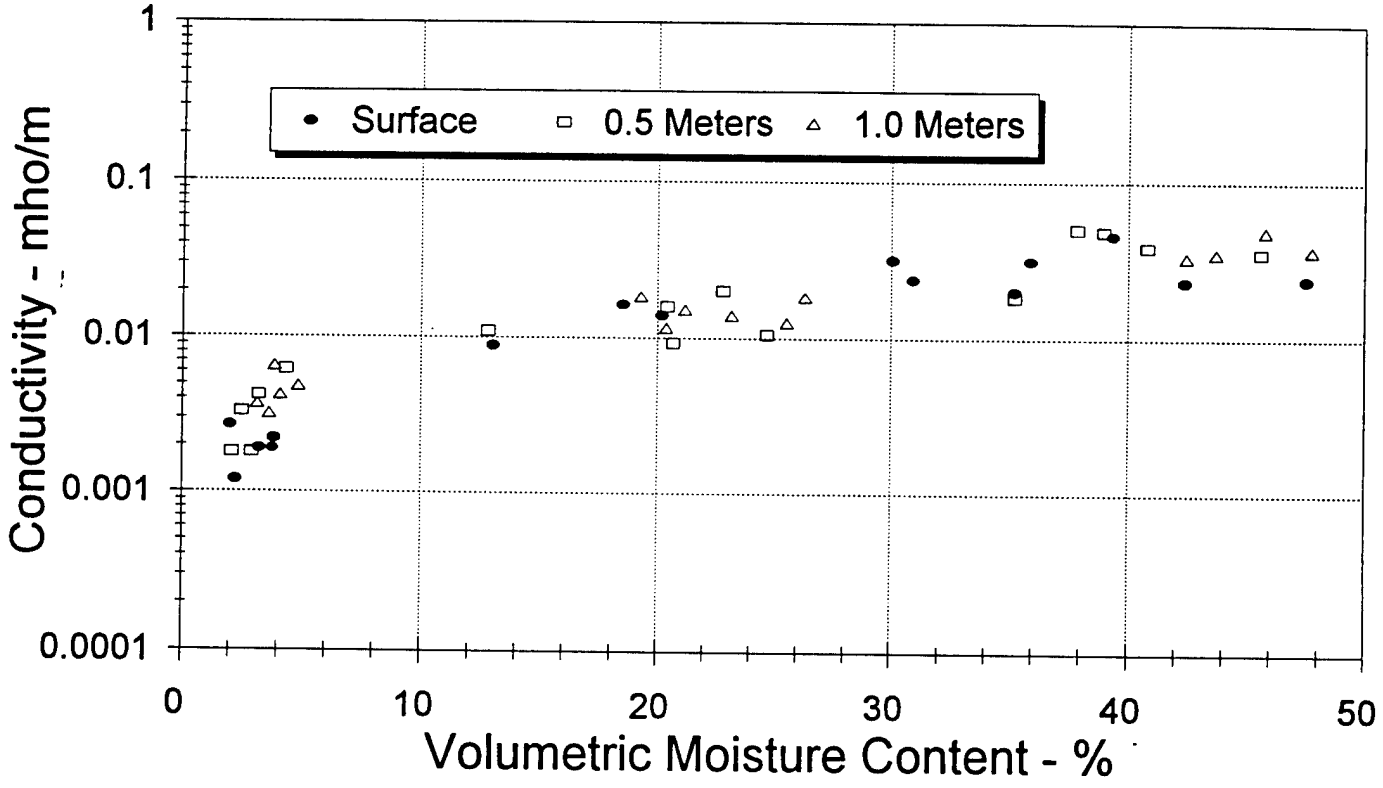
Properties at 200 MHz by Depth

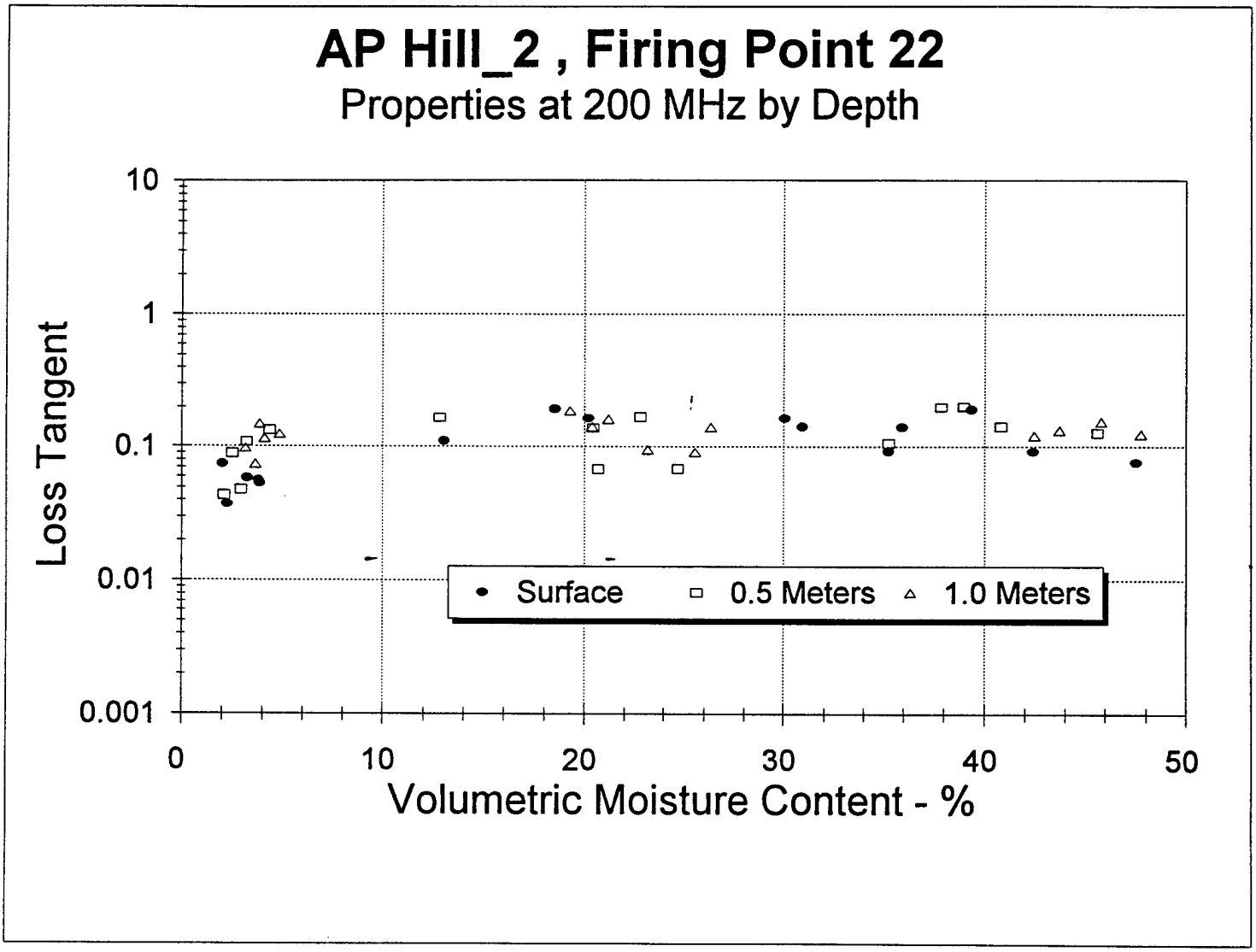


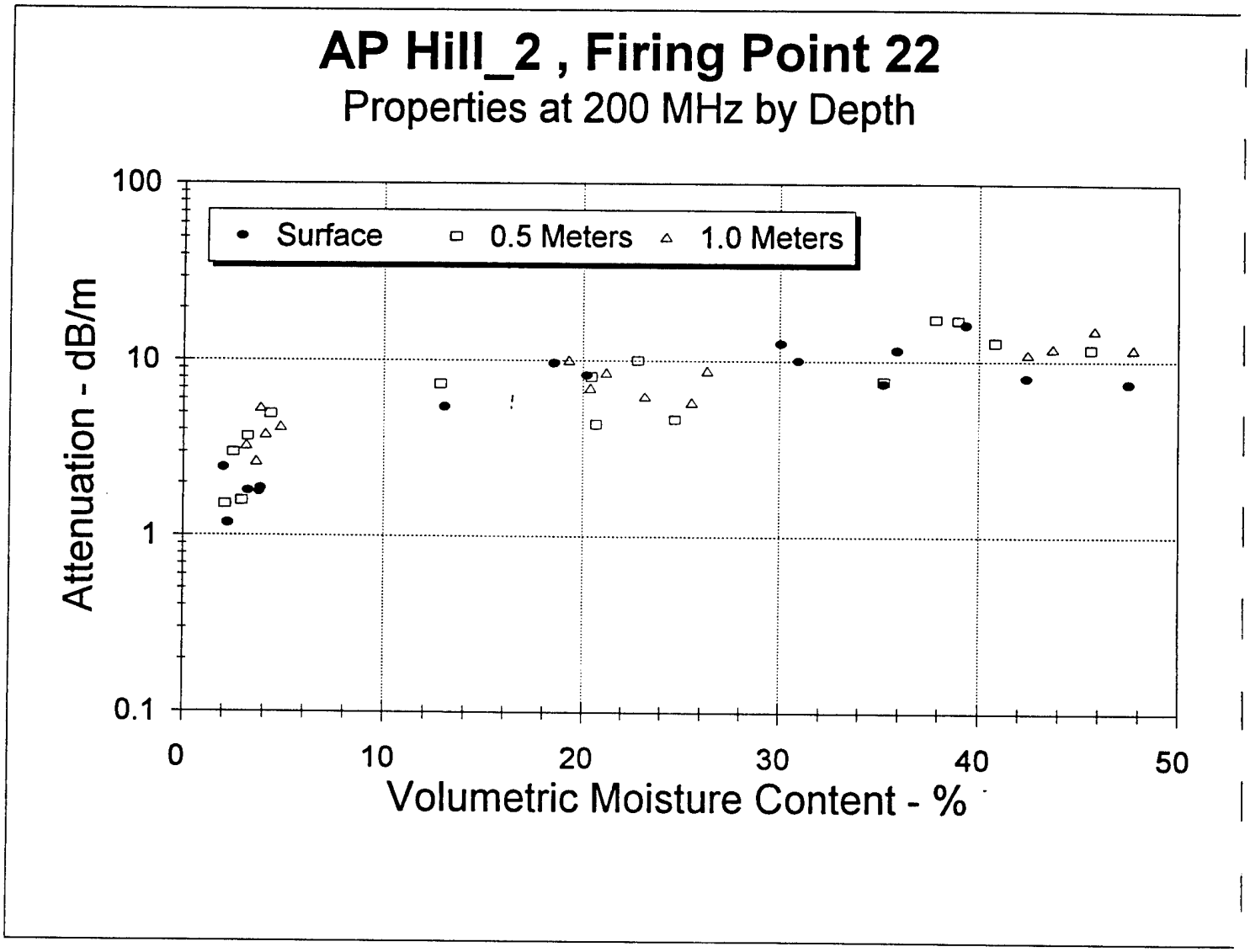

AP Hill_2 , Firing Point 22
Properties at 200 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Im(Dielectric Constant)
0
10
20
30
40
50
Volumetric Moisture Content - %

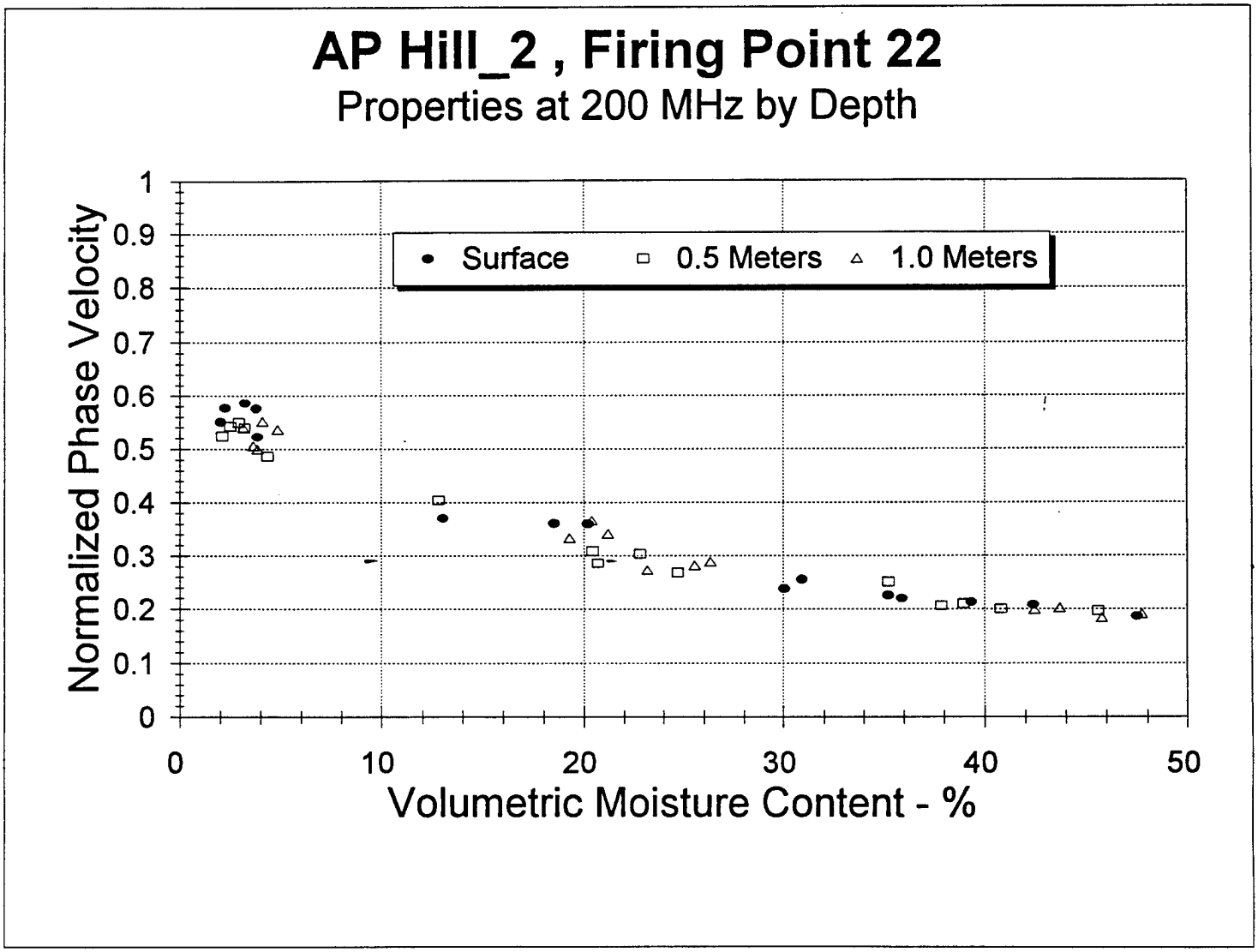
# AP Hill_2 , Firing Point 22

## Properties at 200 MHz by Depth




AP Hill_2 , Firing Point 22
Properties at 200 MHz by Depth
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters


AP Hill_2 , Firing Point 22
Properties at 200 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
Volumetric Moisture Content - %


AP Hill_2 , Firing Point 22
Properties at 200 MHz by Depth
Normalized Phase Velocity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Surface
0.5 Meters
1.0 Meters
0
10
20
30
40
50
Volumetric Moisture Content - %

Fort A.P. Hill_2
Properties at 895 Mhz

Fort AP Hill_2 Soil Properties at 895 MHz

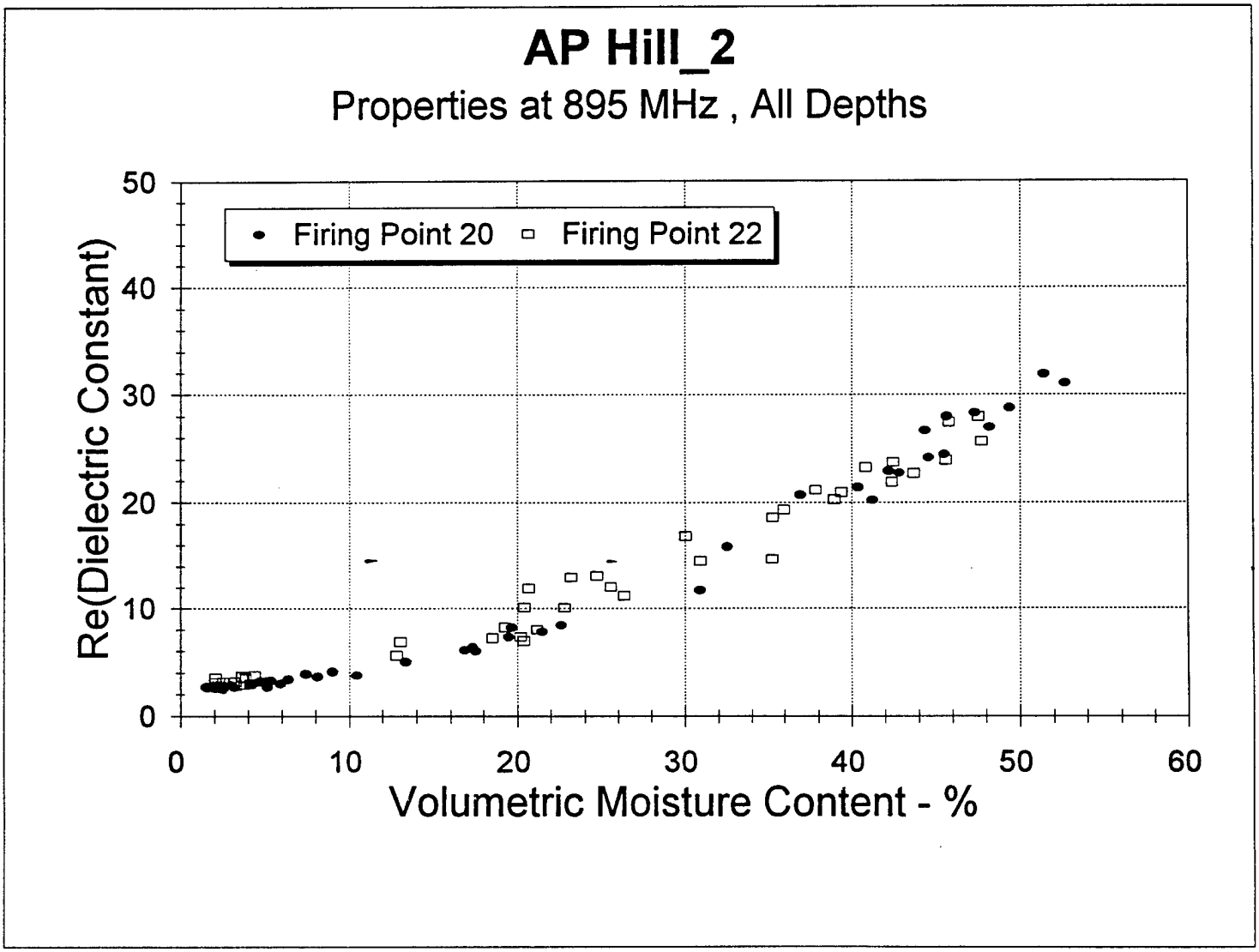
Firing Point 20

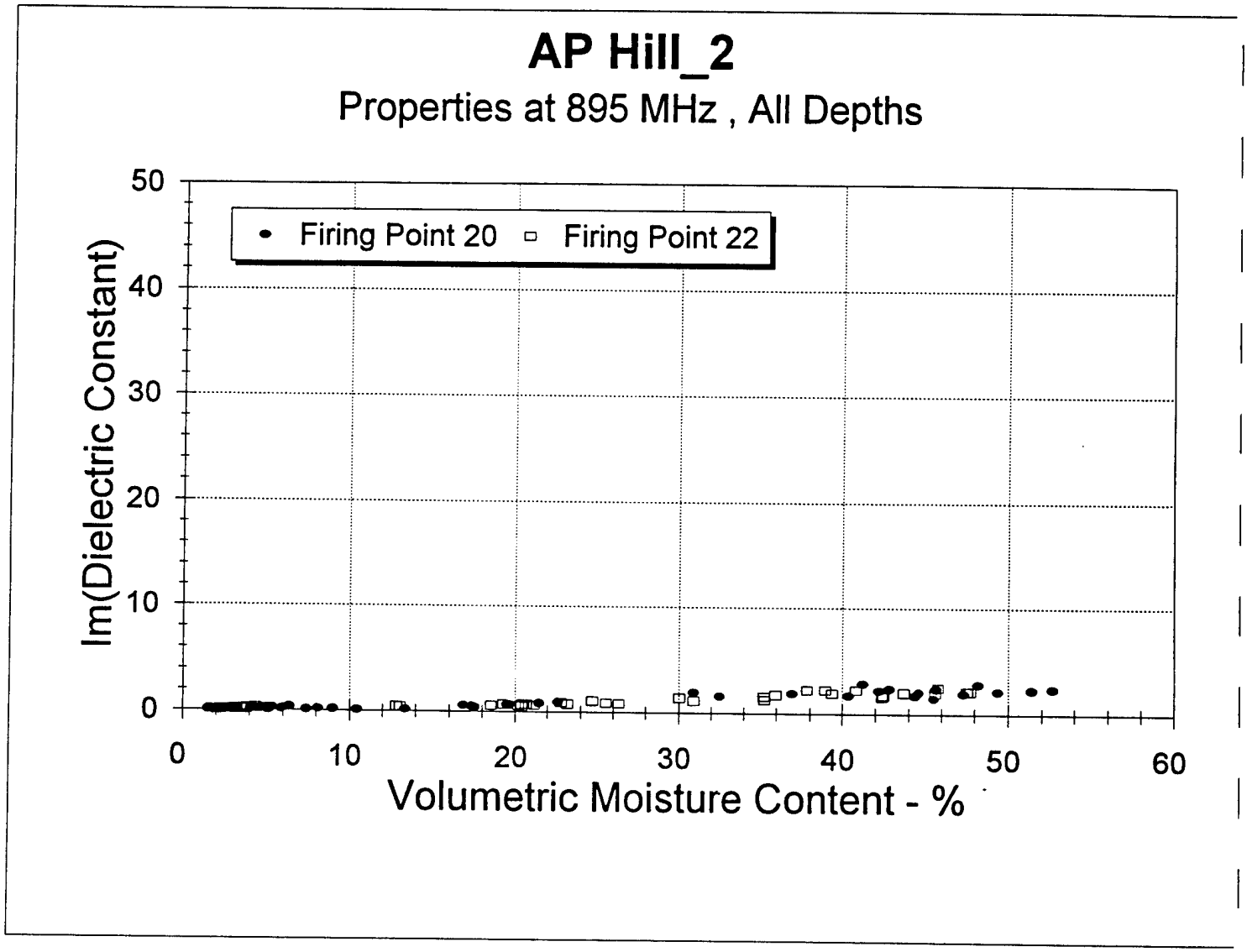
| File Name | Vol Moist | Dry Dens g/cc | Re(eps) | Im(eps) | Cond mho/m | Loss Tan | Attn dB/m | Norm Vel |
|---|---|---|---|---|---|---|---|---|
| 200_1b | 2.57 | 1.40 | 2.79 | 0.18 | 0.009 | 0.06 | 8.78 | 0.60 |
| 200_1d | 2.65 | 1.40 | 2.84 | 0.14 | 0.007 | 0.05 | 6.61 | 0.59 |
| 200_1w | 49.42 | 1.40 | 28.77 | 2.15 | 0.107 | 0.07 | 32.60 | 0.19 |
| 200_2b | 5.97 | 1.21 | 3.00 | 0.14 | 0.007 | 0.05 | 6.55 | 0.58 |
| 200_2d | 2.52 | 1.21 | 2.46 | 0.11 | 0.006 | 0.05 | 5.76 | 0.64 |
| 200_2w | 51.44 | 1.21 | 31.89 | 2.29 | 0.114 | 0.07 | 32.95 | 0.18 |
| 200_sb | 9.01 | 1.39 | 4.12 | 0.17 | 0.008 | 0.04 | 6.71 | 0.49 |
| 200_sd | 2.27 | 1.39 | 2.72 | 0.07 | 0.003 | 0.02 | 3.32 | 0.61 |
| 200_sw | 47.36 | 1.39 | 28.36 | 1.96 | 0.098 | 0.07 | 29.98 | 0.19 |
| 20122_1b | 30.94 | 1.53 | 11.76 | 1.97 | 0.098 | 0.17 | 46.58 | 0.29 |
| 20122_1d | 6.41 | 1.53 | 3.39 | 0.39 | 0.020 | 0.12 | 17.30 | 0.54 |
| 20122_1w | 41.25 | 1.53 | 20.25 | 2.85 | 0.142 | 0.14 | 51.52 | 0.22 |
| 20122_2b | 16.89 | 1.37 | 6.14 | 0.60 | 0.030 | 0.10 | 19.69 | 0.40 |
| 20122_2d | 2.98 | 1.37 | 2.93 | 0.20 | 0.010 | 0.07 | 9.48 | 0.58 |
| 20122_2w | 48.22 | 1.37 | 27.06 | 2.83 | 0.141 | 0.10 | 44.21 | 0.19 |
| 20122_sb | 17.37 | 1.47 | 6.43 | 0.49 | 0.025 | 0.08 | 15.85 | 0.39 |
| 20122_sd | 3.19 | 1.47 | 2.72 | 0.08 | 0.004 | 0.03 | 3.88 | 0.61 |
| 20122_sw | 40.39 | 1.47 | 21.43 | 1.71 | 0.085 | 0.08 | 30.10 | 0.22 |
| 20123_1b | 8.11 | 1.33 | 3.67 | 0.19 | 0.009 | 0.05 | 7.91 | 0.52 |
| 20123_1d | 1.61 | 1.33 | 2.59 | 0.14 | 0.007 | 0.05 | 6.88 | 0.62 |
| 20123_1w | 52.69 | 1.33 | 31.07 | 2.41 | 0.120 | 0.08 | 35.11 | 0.18 |
| 20123_2b | 21.49 | 1.66 | 7.82 | 0.80 | 0.040 | 0.10 | 23.20 | 0.36 |
| 20123_2d | 4.55 | 1.66 | 3.12 | 0.21 | 0.010 | 0.07 | 9.52 | 0.57 |
| 20123_2w | 32.55 | 1.66 | 15.84 | 1.61 | 0.080 | 0.10 | 32.87 | 0.25 |
| 20123_sb | 19.71 | 1.54 | 8.24 | 0.70 | 0.035 | 0.08 | 19.75 | 0.35 |
| 20123_sd | 1.95 | 1.54 | 2.81 | 0.06 | 0.003 | 0.02 | 2.99 | 0.60 |
| 20123_sw | 36.96 | 1.54 | 20.71 | 1.90 | 0.094 | 0.09 | 33.87 | 0.22 |
| 2027_1b | 7.44 | 1.53 | 3.94 | 0.13 | 0.006 | 0.03 | 5.15 | 0.50 |
| 2027_1d | 1.54 | 1.53 | 2.69 | 0.06 | 0.003 | 0.02 | 2.97 | 0.61 |
| 2027_1w | 44.38 | 1.53 | 26.75 | 1.72 | 0.086 | 0.06 | 27.11 | 0.19 |
| 2027_2b | 22.63 | 1.53 | 8.43 | 0.93 | 0.047 | 0.11 | 26.15 | 0.34 |
| 2027_2d | 5.34 | 1.53 | 3.29 | 0.30 | 0.015 | 0.09 | 13.32 | 0.55 |
| 2027_2w | 42.86 | 1.53 | 22.80 | 2.38 | 0.119 | 0.10 | 40.60 | 0.21 |
| 2027_sb | 10.49 | 1.44 | 3.77 | 0.13 | 0.006 | 0.03 | 5.40 | 0.51 |
| 2027_sd | 5.16 | 1.44 | 2.68 | 0.07 | 0.003 | 0.03 | 3.41 | 0.61 |
| 2027_sw | 45.55 | 1.44 | 24.49 | 1.53 | 0.076 | 0.06 | 25.08 | 0.20 |
| 2065_1b | 17.55 | 1.47 | 6.03 | 0.43 | 0.021 | 0.07 | 14.22 | 0.41 |
| 2065_1d | 4.15 | 1.47 | 2.96 | 0.19 | 0.010 | 0.07 | 9.21 | 0.58 |
| 2065_1w | 44.58 | 1.47 | 24.19 | 2.02 | 0.101 | 0.08 | 33.39 | 0.20 |
| 2065_2b | 19.52 | 1.48 | 7.36 | 0.68 | 0.034 | 0.09 | 20.53 | 0.37 |
| 2065_2d | 4.91 | 1.48 | 3.12 | 0.24 | 0.012 | 0.08 | 10.90 | 0.57 |
| 2065_2w | 42.22 | 1.48 | 22.96 | 2.22 | 0.111 | 0.10 | 37.69 | 0.21 |
| 2065_sb | 13.39 | 1.37 | 5.03 | 0.19 | 0.010 | 0.04 | 6.92 | 0.45 |
| 2065_sd | 2.09 | 1.37 | 2.55 | 0.04 | 0.002 | 0.02 | 2.15 | 0.63 |
| 2065_sw | 45.70 | 1.37 | 27.99 | 2.41 | 0.120 | 0.09 | 37.07 | 0.19 |

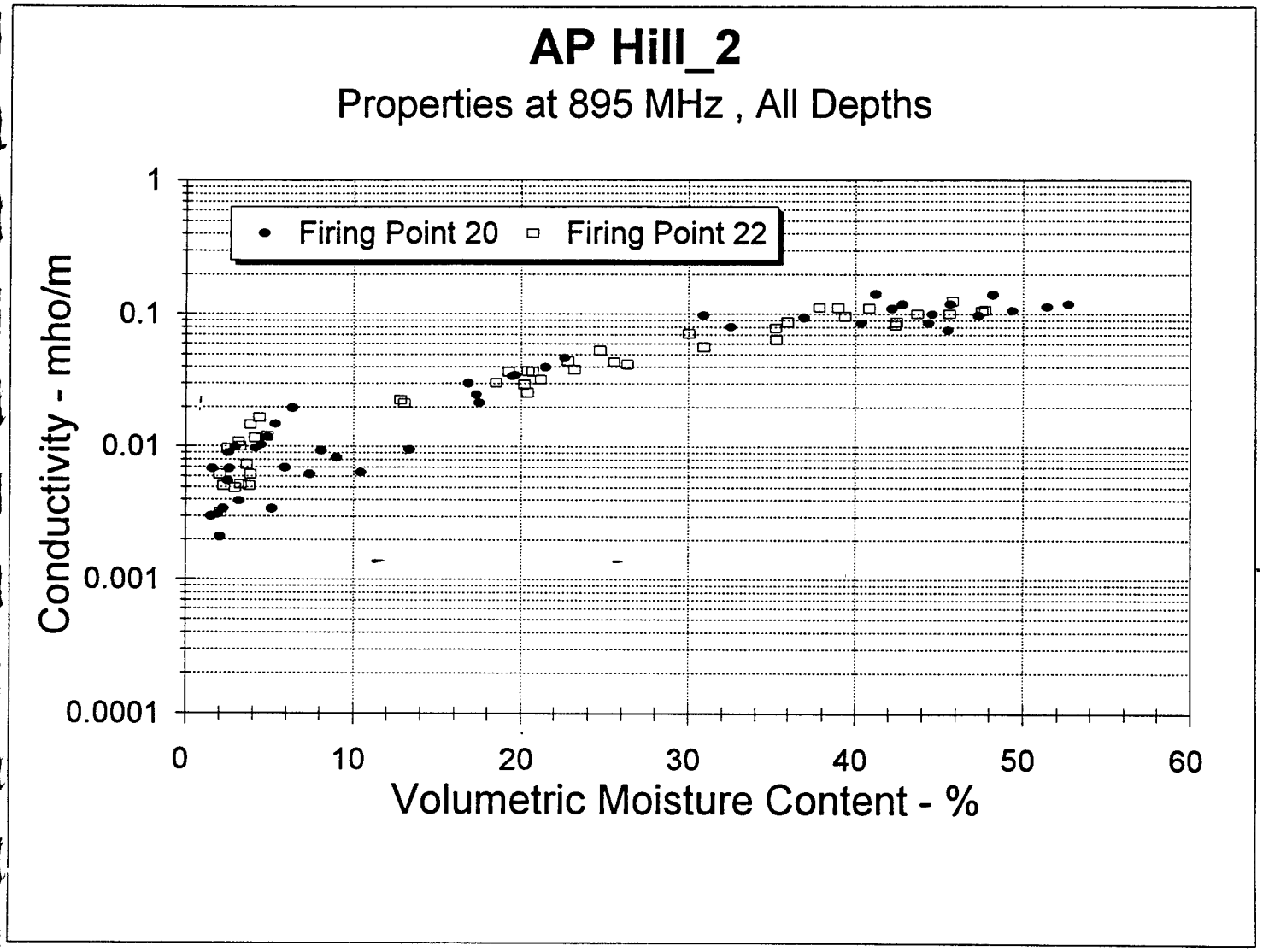
Fort AP Hill_2 Soil Properties at 895 MHz

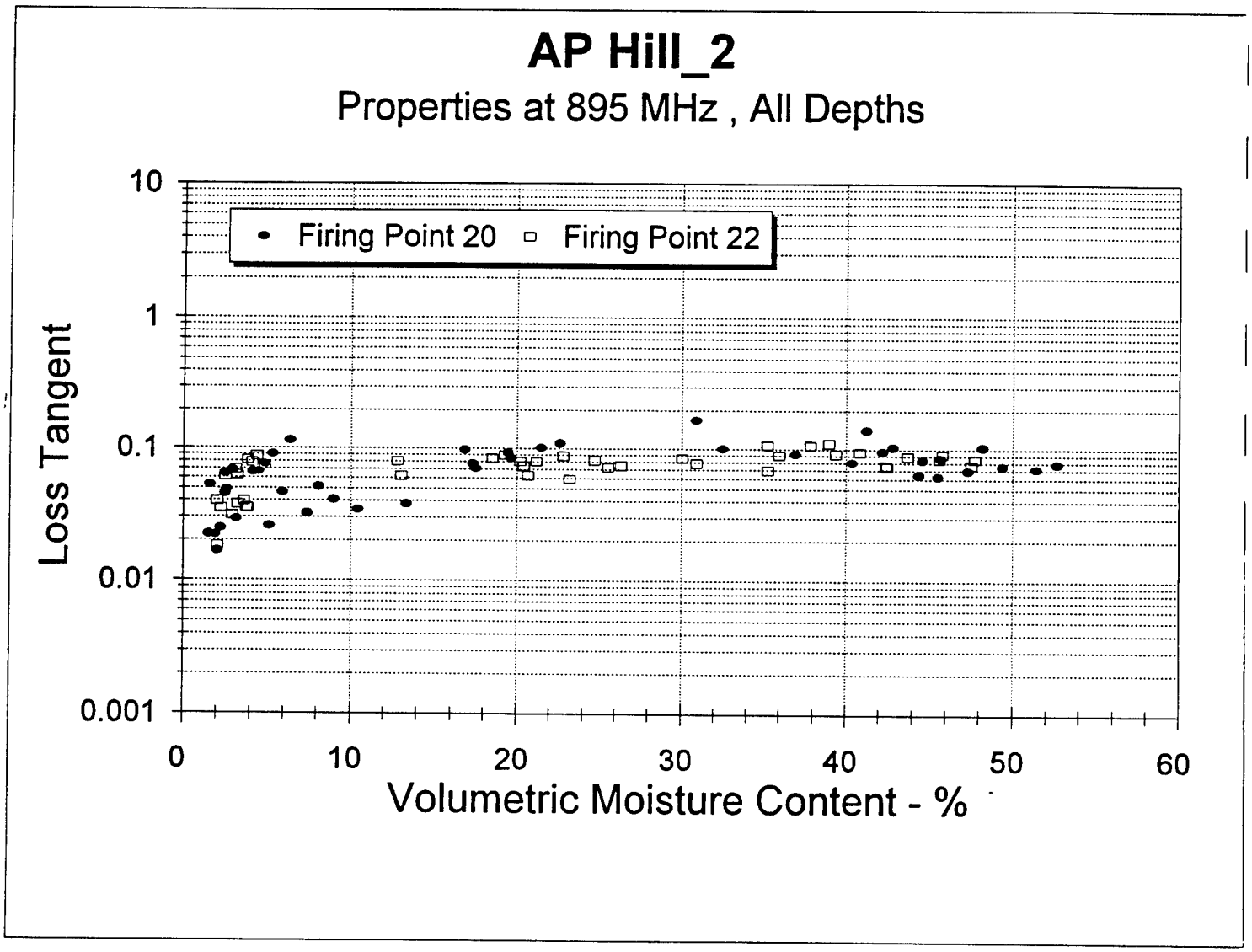
Firing Point 22

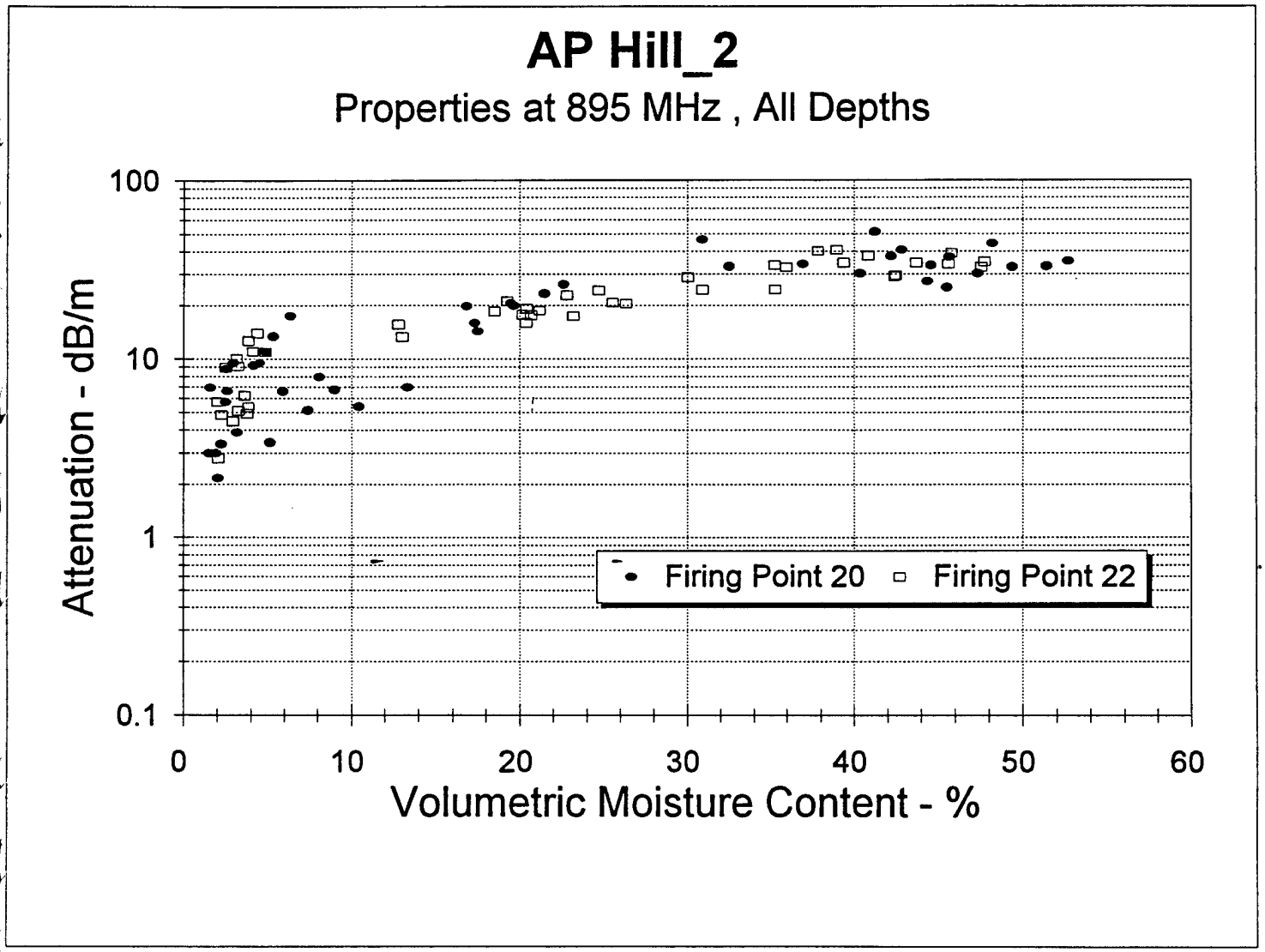
| File Name | Vol Moist | Dry Dens g/cc | Re(eps) | Im(eps) | Cond mho/m | Loss Tan | Attn dB/m | Norm Vel |
|---|---|---|---|---|---|---|---|---|
| 22122_1b | 19.30 | 1.53 | 8.28 | 0.74 | 0.037 | 0.09 | 21.01 | 0.35 |
| 22122_1d | 3.88 | 1.53 | 3.62 | 0.30 | 0.015 | 0.08 | 12.63 | 0.53 |
| 22122_1w | 45.79 | 1.53 | 27.52 | 2.52 | 0.125 | 0.09 | 39.06 | 0.19 |
| 22122_2b | 20.45 | 1.83 | 10.15 | 0.74 | 0.037 | 0.07 | 19.01 | 0.31 |
| 22122_2d | 2.94 | 1.83 | 3.20 | 0.10 | 0.005 | 0.03 | 4.49 | 0.56 |
| 22122_2w | 35.24 | 1.83 | 14.72 | 1.58 | 0.079 | 0.11 | 33.54 | 0.26 |
| 22122_sb | 13.05 | 1.69 | 6.91 | 0.43 | 0.021 | 0.06 | 13.24 | 0.38 |
| 22122_sd | 2.04 | 1.69 | 3.16 | 0.13 | 0.006 | 0.04 | 5.73 | 0.56 |
| 22122_sw | 35.25 | 1.69 | 18.63 | 1.29 | 0.064 | 0.07 | 24.37 | 0.23 |
| 22123_1b | 21.20 | 1.53 | 8.05 | 0.65 | 0.032 | 0.08 | 18.57 | 0.35 |
| 22123_1d | 4.87 | 1.53 | 3.23 | 0.24 | 0.012 | 0.07 | 10.90 | 0.56 |
| 22123_1w | 43.69 | 1.53 | 22.73 | 2.03 | 0.101 | 0.09 | 34.59 | 0.21 |
| 22123_2b | 12.82 | 1.51 | 5.64 | 0.45 | 0.023 | 0.08 | 15.48 | 0.42 |
| 22123_2d | 3.22 | 1.51 | 3.20 | 0.20 | 0.010 | 0.06 | 9.11 | 0.56 |
| 22123_2w | 45.59 | 1.51 | 23.97 | 2.04 | 0.101 | 0.08 | 33.81 | 0.20 |
| 22123_sb | 18.55 | 1.55 | 7.28 | 0.61 | 0.030 | 0.08 | 18.43 | 0.37 |
| 22123_sd | 3.80 | 1.55 | 2.91 | 0.10 | 0.005 | 0.04 | 4.93 | 0.59 |
| 22123_sw | 39.36 | 1.55 | 20.99 | 1.95 | 0.097 | 0.09 | 34.56 | 0.22 |
| 2227_1b | 26.33 | 1.51 | 11.26 | 0.84 | 0.042 | 0.07 | 20.36 | 0.30 |
| 2227_1d | 3.15 | 1.51 | 3.17 | 0.22 | 0.011 | 0.07 | 10.05 | 0.56 |
| 2227_1w | 42.47 | 1.51 | 23.81 | 1.76 | 0.087 | 0.07 | 29.29 | 0.20 |
| 2227_2b | 37.85 | 1.66 | 21.20 | 2.27 | 0.113 | 0.11 | 40.12 | 0.22 |
| 2227_2d | 4.37 | 1.66 | 3.81 | 0.33 | 0.017 | 0.09 | 13.91 | 0.51 |
| 2227_2w | 38.96 | 1.66 | 20.33 | 2.26 | 0.113 | 0.11 | 40.76 | 0.22 |
| 2227_sb | 47.54 | 1.31 | 28.01 | 2.13 | 0.106 | 0.08 | 32.72 | 0.19 |
| 2227_sd | 2.27 | 1.31 | 2.92 | 0.10 | 0.005 | 0.03 | 4.85 | 0.59 |
| 2227_sw | 42.39 | 1.31 | 21.97 | 1.67 | 0.083 | 0.08 | 28.91 | 0.21 |
| 222_1b | 20.41 | 1.40 | 7.01 | 0.52 | 0.026 | 0.07 | 15.88 | 0.38 |
| 222_1d | 4.12 | 1.40 | 2.99 | 0.23 | 0.012 | 0.08 | 11.02 | 0.58 |
| 222_1w | 47.74 | 1.40 | 25.74 | 2.18 | 0.108 | 0.08 | 34.88 | 0.20 |
| 222_2b | 22.82 | 1.57 | 10.11 | 0.89 | 0.044 | 0.09 | 22.77 | 0.31 |
| 222_2d | 2.51 | 1.57 | 3.18 | 0.20 | 0.010 | 0.06 | 8.92 | 0.56 |
| 222_2w | 40.82 | 1.57 | 23.32 | 2.24 | 0.111 | 0.10 | 37.71 | 0.21 |
| 222_sb | 20.23 | 1.55 | 7.38 | 0.59 | 0.029 | 0.08 | 17.65 | 0.37 |
| 222_sd | 3.26 | 1.55 | 2.82 | 0.11 | 0.005 | 0.04 | 5.12 | 0.60 |
| 222_sw | 35.92 | 1.55 | 19.37 | 1.76 | 0.088 | 0.09 | 32.47 | 0.23 |
| 2265_1b | 23.21 | 1.99 | 13.00 | 0.77 | 0.038 | 0.06 | 17.27 | 0.28 |
| 2265_1d | 3.65 | 1.99 | 3.72 | 0.15 | 0.007 | 0.04 | 6.22 | 0.52 |
| 2265_1w | 25.57 | 1.99 | 12.08 | 0.88 | 0.044 | 0.07 | 20.61 | 0.29 |
| 2265_2b | 20.71 | 1.94 | 11.93 | 0.74 | 0.037 | 0.06 | 17.47 | 0.29 |
| 2265_2d | 2.09 | 1.94 | 3.56 | 0.06 | 0.003 | 0.02 | 2.78 | 0.53 |
| 2265_2w | 24.72 | 1.94 | 13.13 | 1.08 | 0.054 | 0.08 | 24.14 | 0.28 |
| 2265_sb | 30.08 | 1.82 | 16.85 | 1.44 | 0.072 | 0.09 | 28.56 | 0.24 |
| 2265_sd | 3.87 | 1.82 | 3.54 | 0.12 | 0.006 | 0.04 | 5.38 | 0.53 |
| 2265_sw | 30.94 | 1.82 | 14.56 | 1.14 | 0.057 | 0.08 | 24.35 | 0.26 |

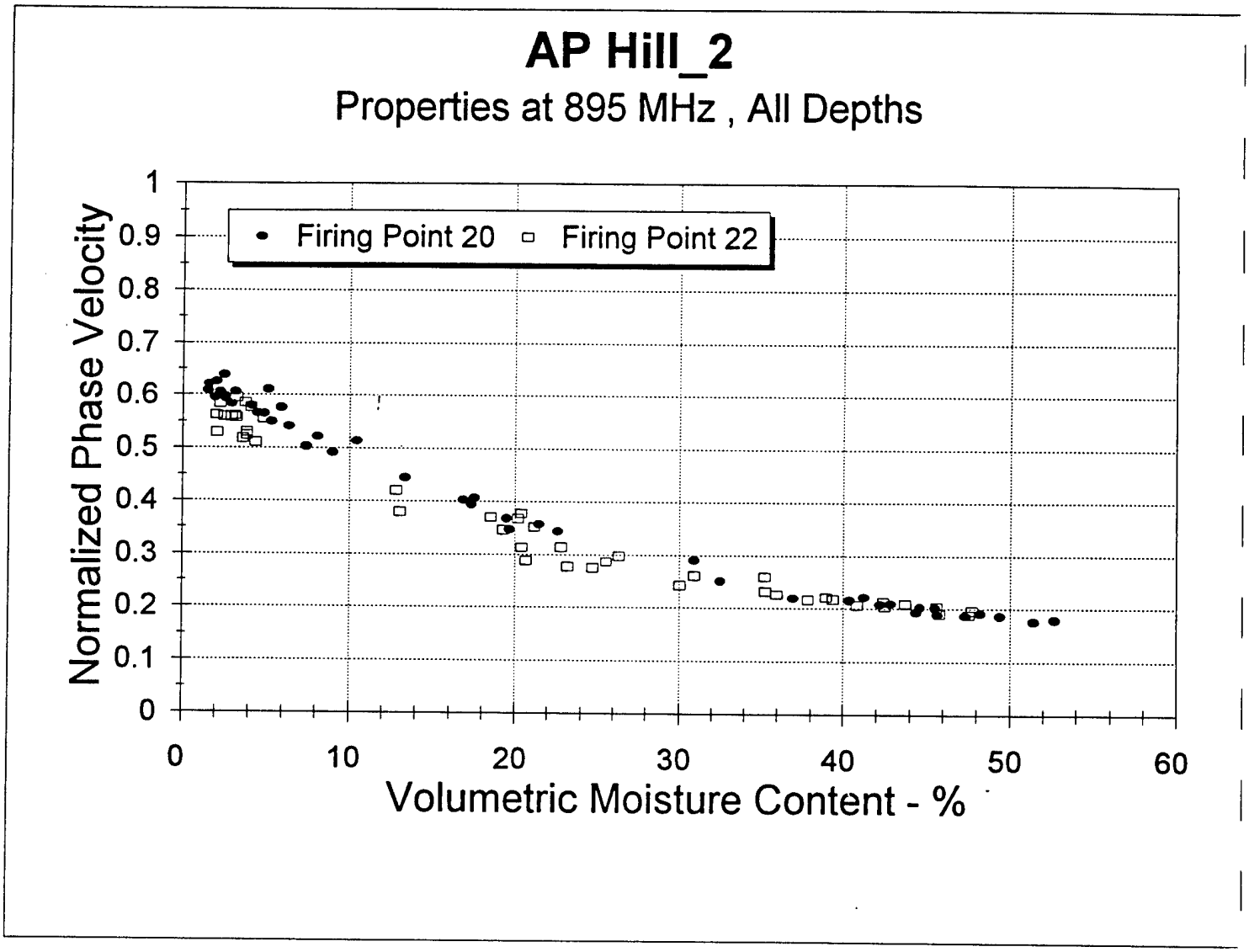

AP Hill_2
Properties at 895 MHz , All Depths
Firing Point 20
Firing Point 22
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50
60

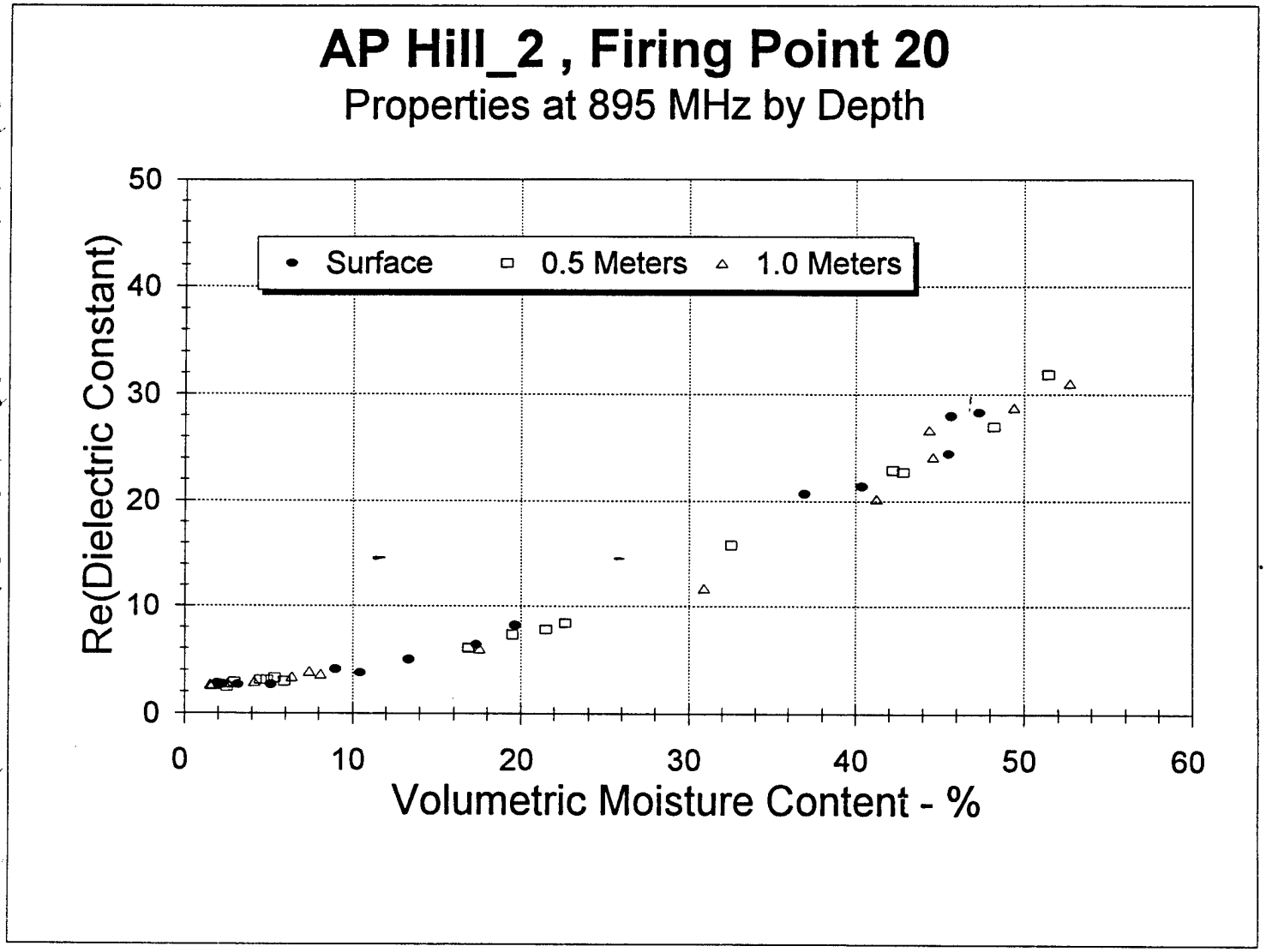

AP Hill_2
Properties at 895 MHz , All Depths
Firing Point 20
Firing Point 22
Im(Dielectric Constant)
0
10
20
30
40
50
0
10
20
30
40
50
60
Volumetric Moisture Content - %

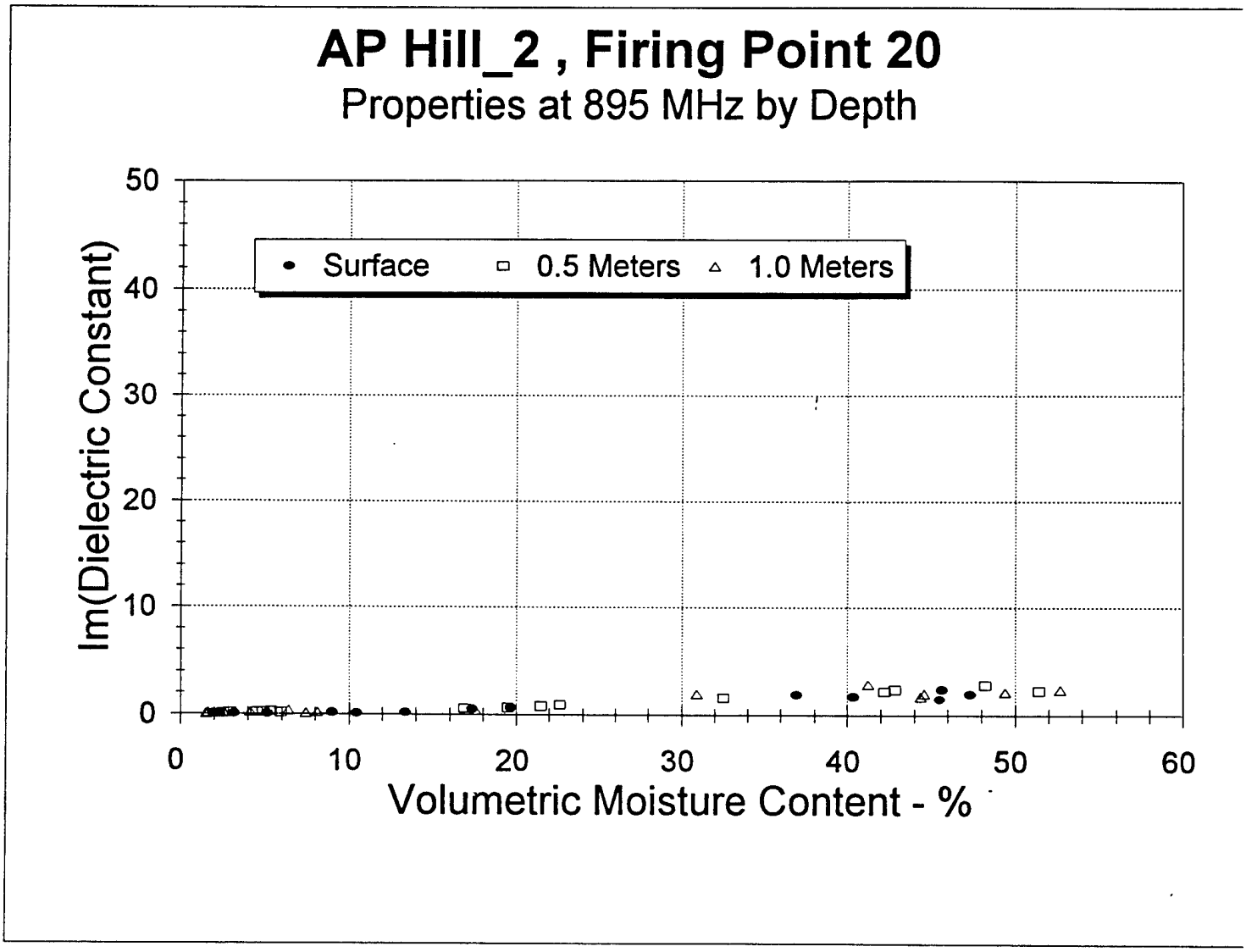

AP Hill_2
Properties at 895 MHz , All Depths
Firing Point 20
Firing Point 22
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

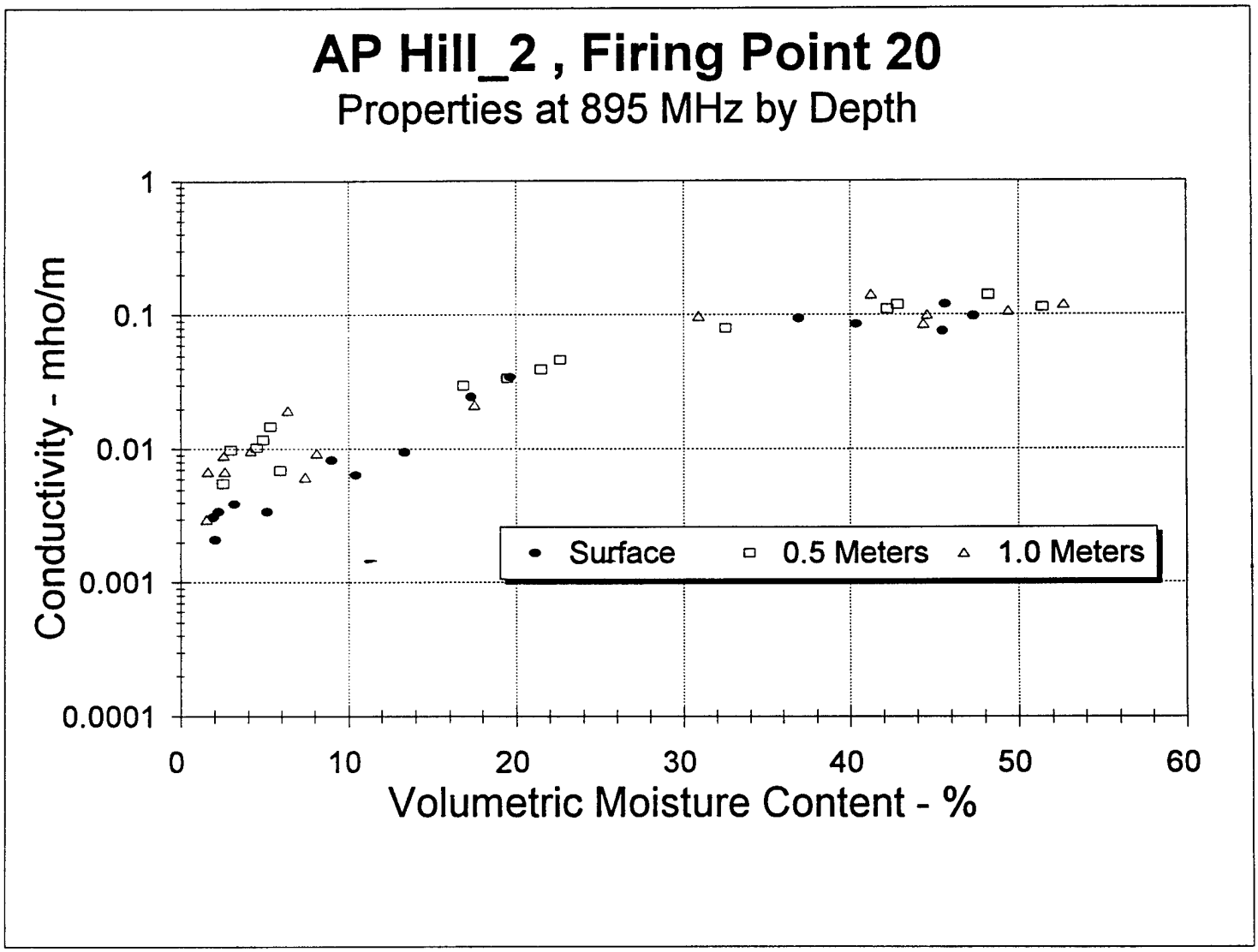

AP Hill_2
Properties at 895 MHz , All Depths
Firing Point 20
Firing Point 22
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
Volumetric Moisture Content - %

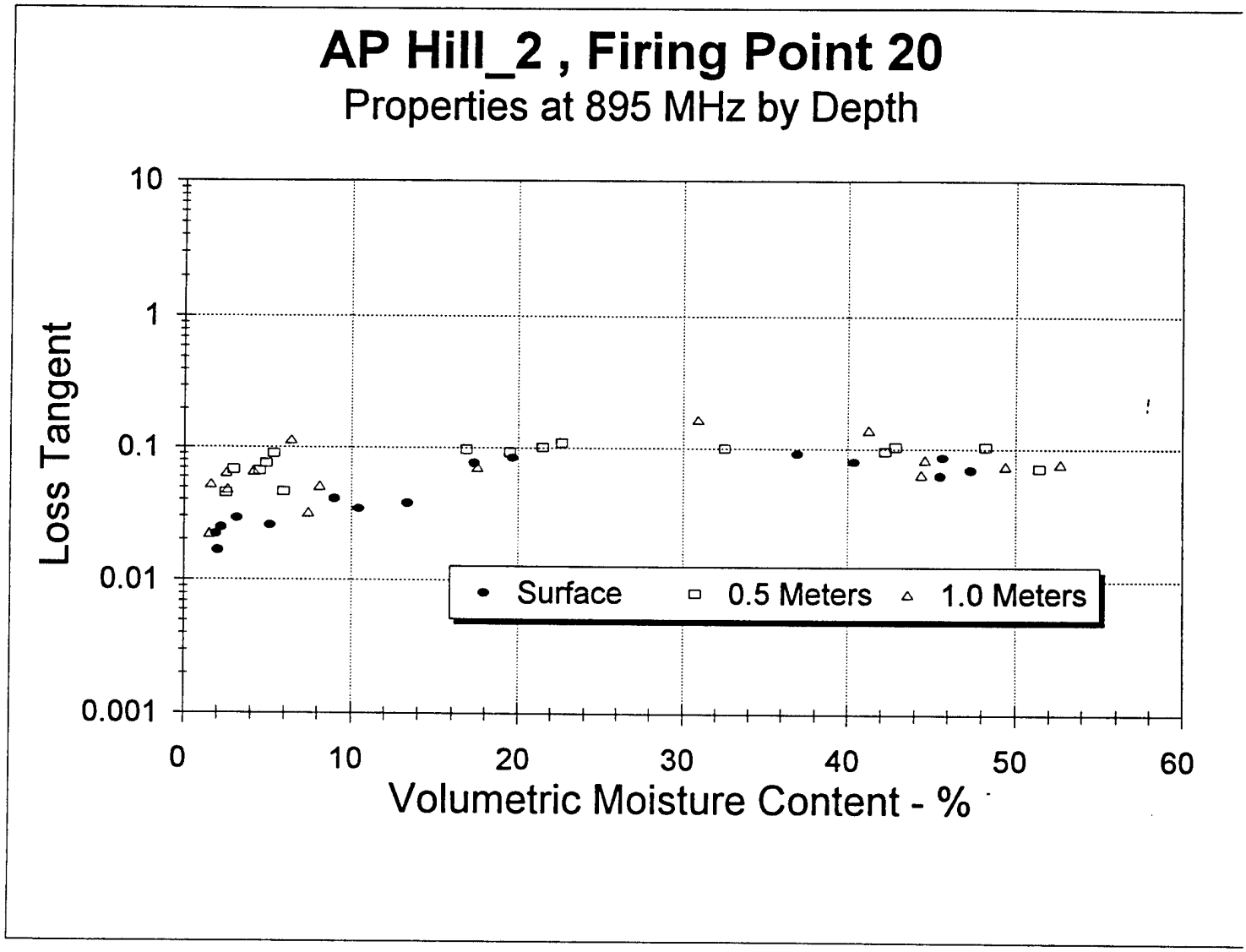

AP Hill_2
Properties at 895 MHz , All Depths
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
60
Volumetric Moisture Content - %
Firing Point 20
Firing Point 22

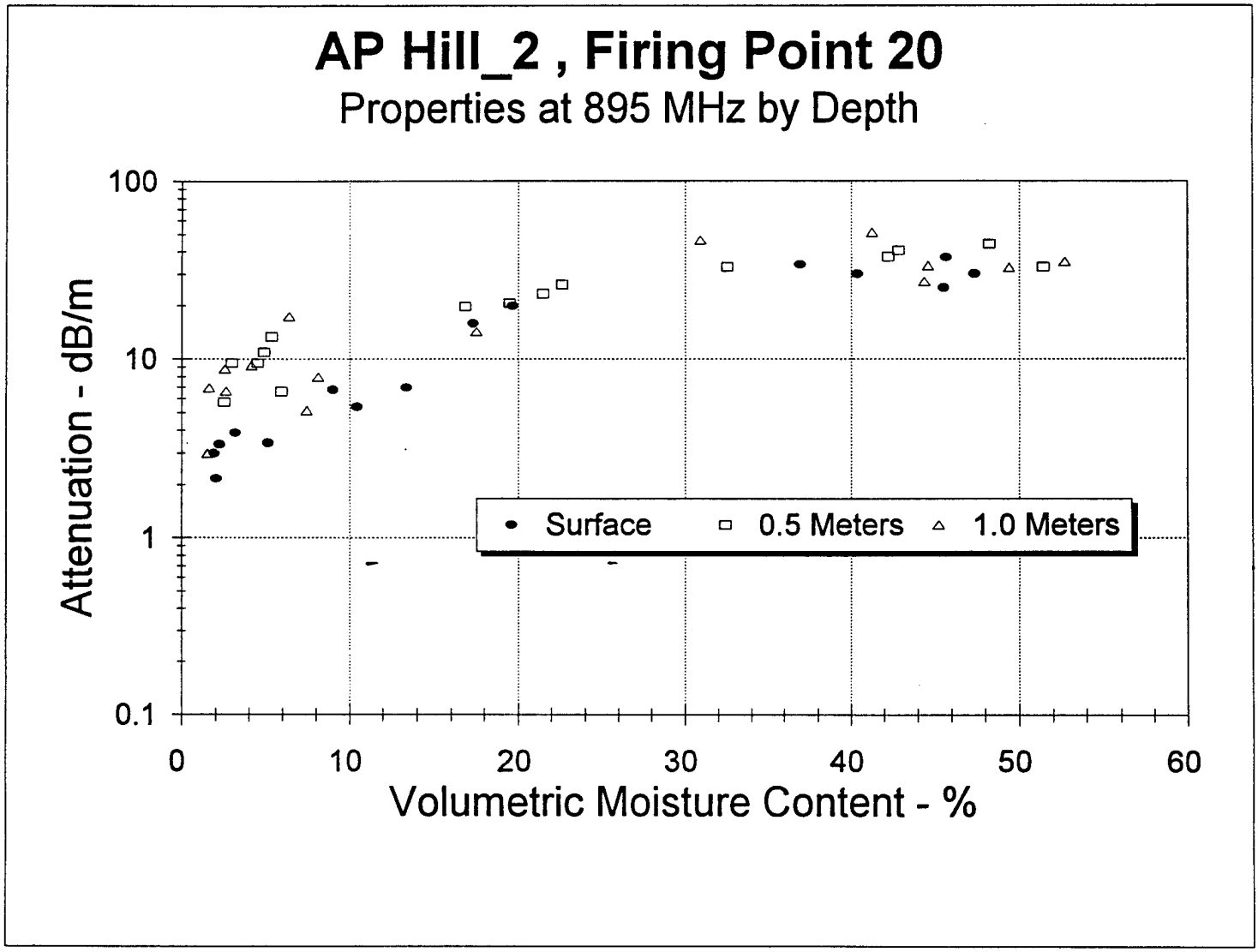

AP Hill_2
Properties at 895 MHz , All Depths
Firing Point 20
Firing Point 22
Normalized Phase Velocity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
Volumetric Moisture Content - %


AP Hill_2 , Firing Point 20
Properties at 895 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50
60


AP Hill_2 , Firing Point 20
Properties at 895 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Im(Dielectric Constant)
50
40
30
20
10
0
0
10
20
30
40
50
60
Volumetric Moisture Content - %

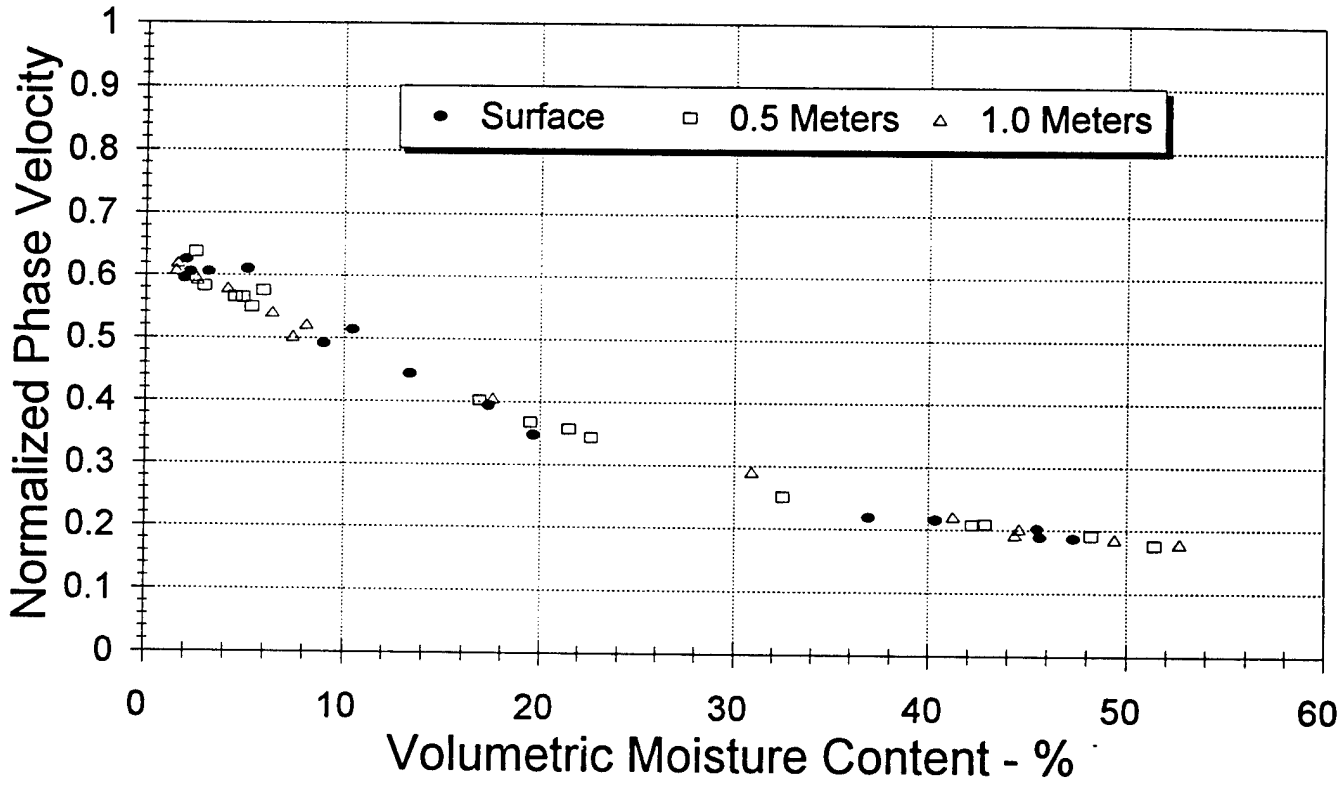

AP Hill_2 , Firing Point 20
Properties at 895 MHz by Depth
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters

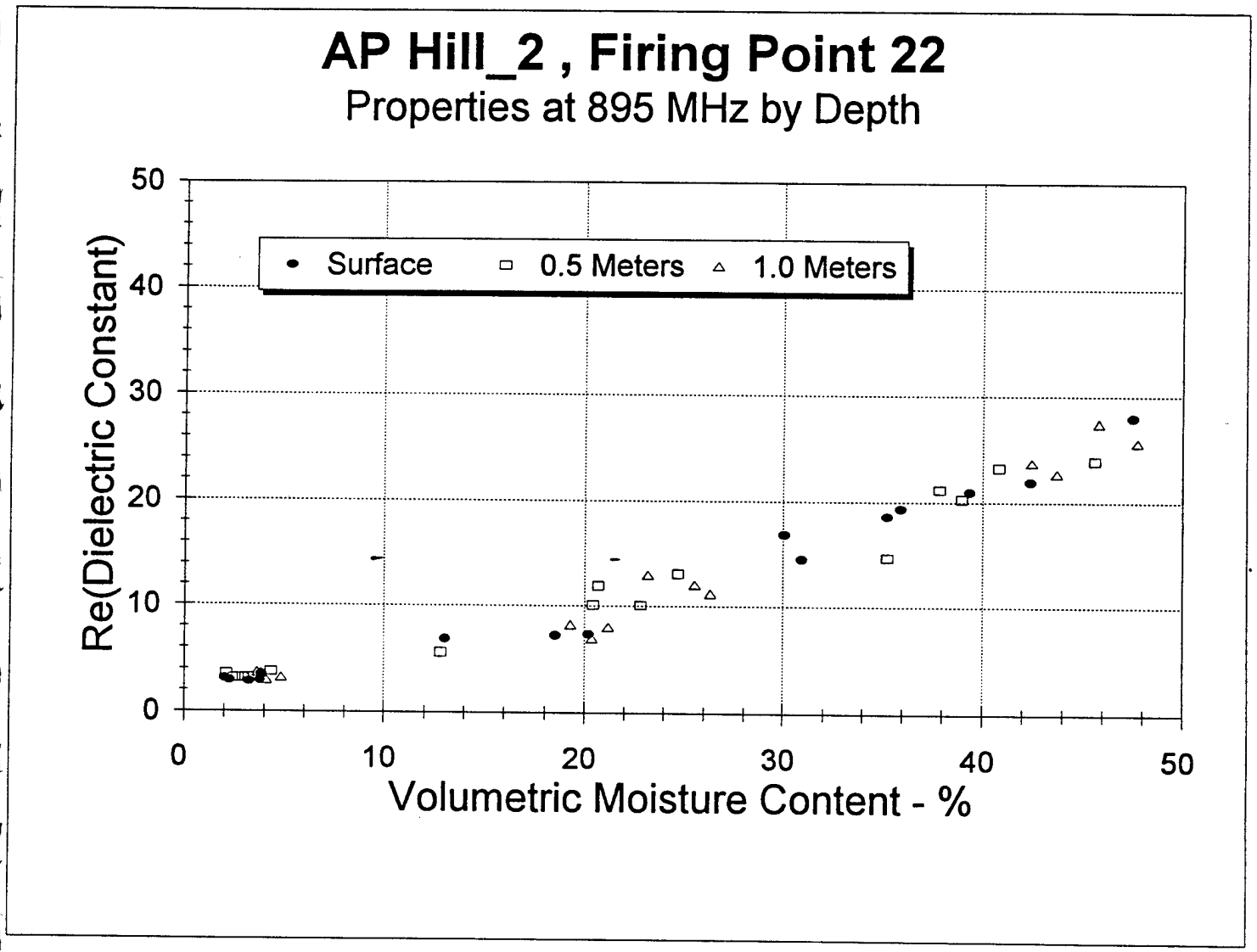

AP Hill_2 , Firing Point 20
Properties at 895 MHz by Depth
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters

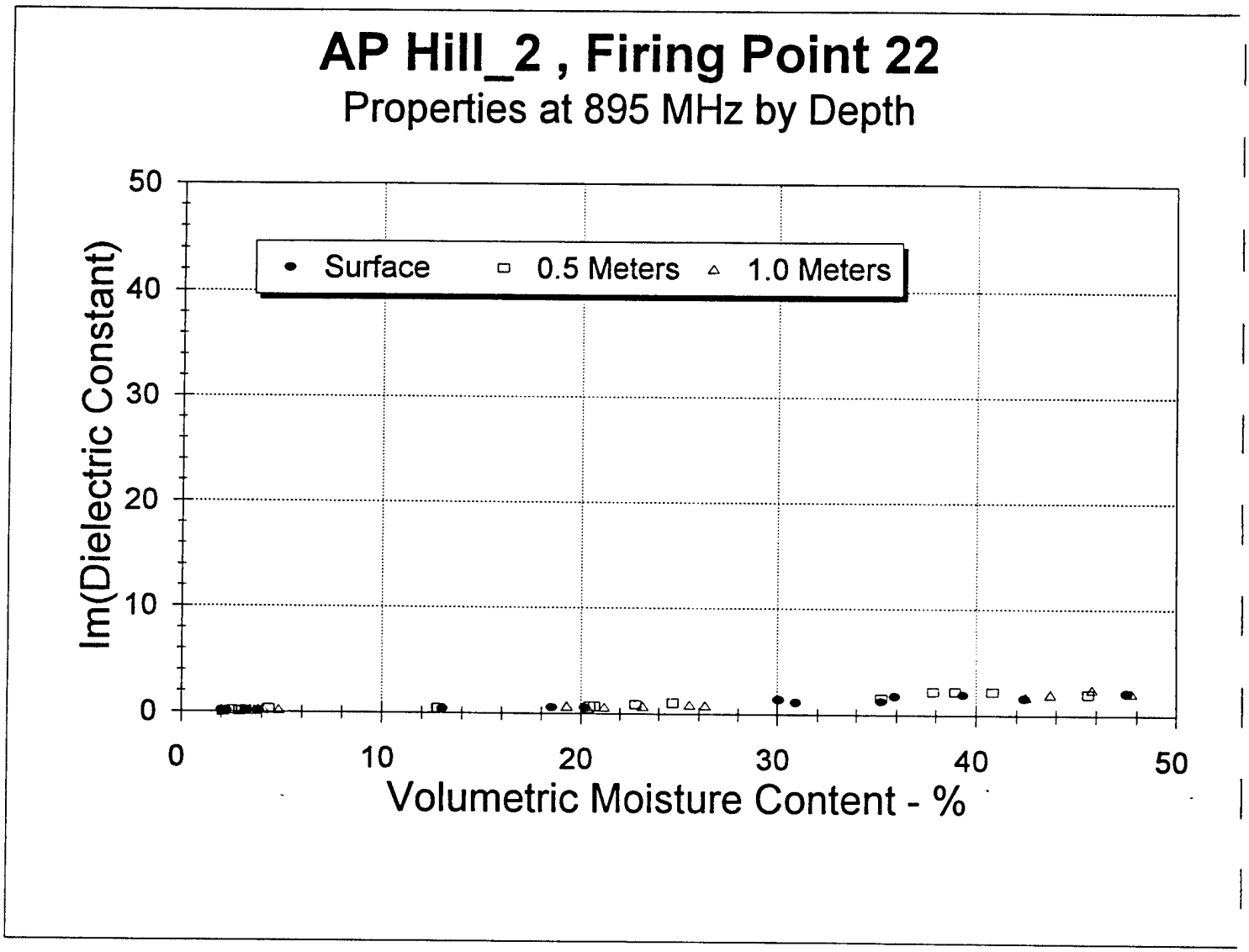

AP Hill_2 , Firing Point 20
Properties at 895 MHz by Depth
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
60
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters

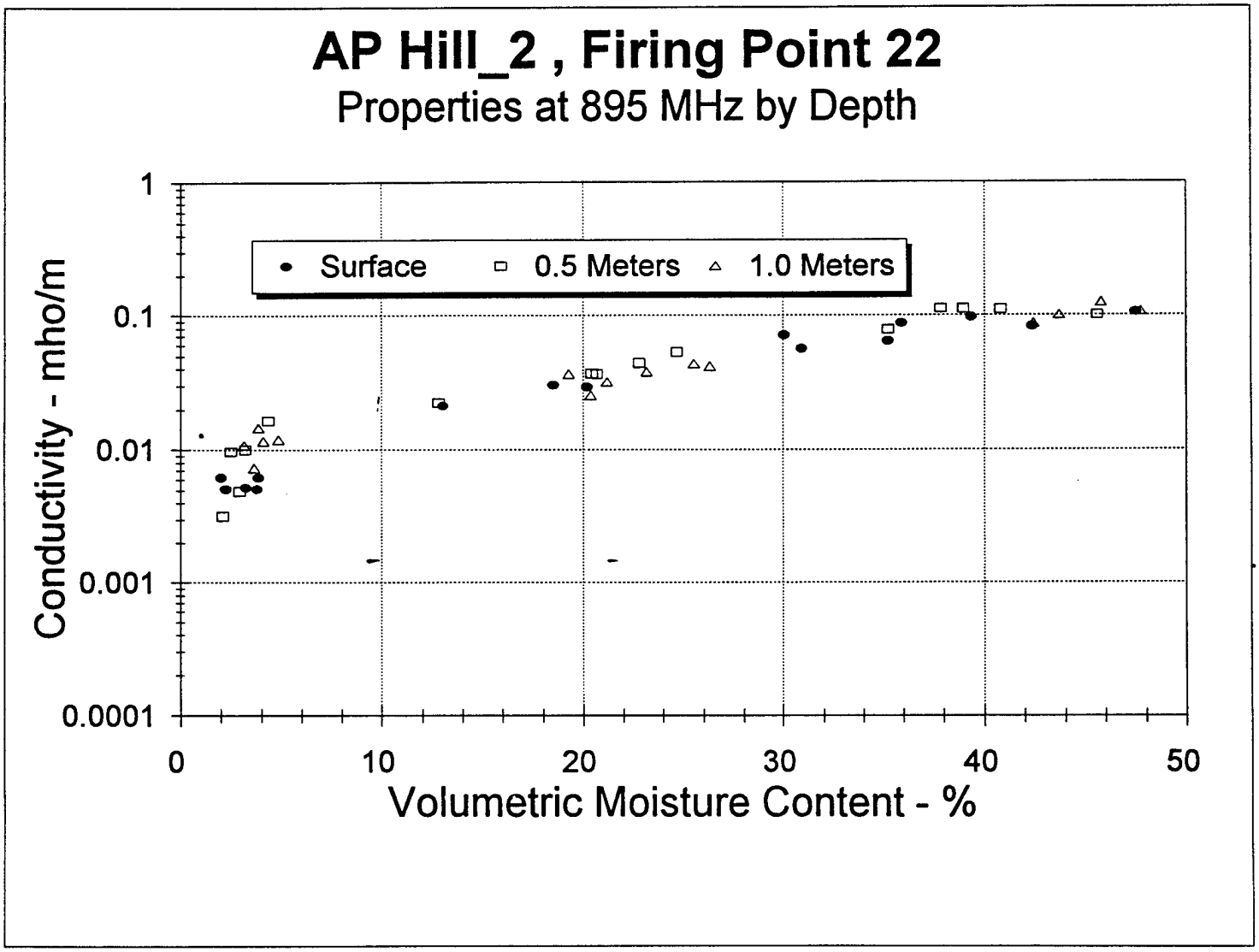
# AP Hill_2 , Firing Point 20

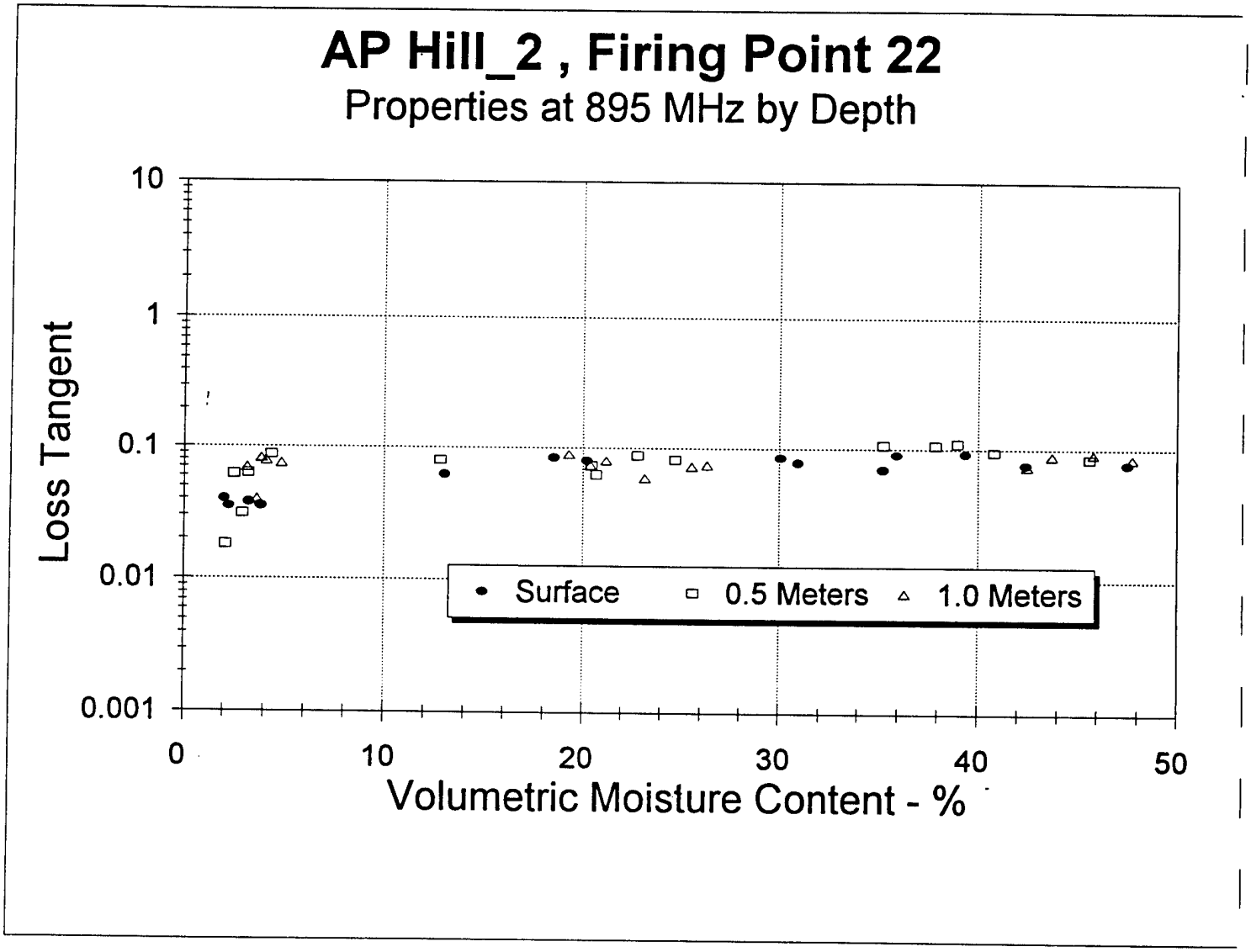
## Properties at 895 MHz by Depth

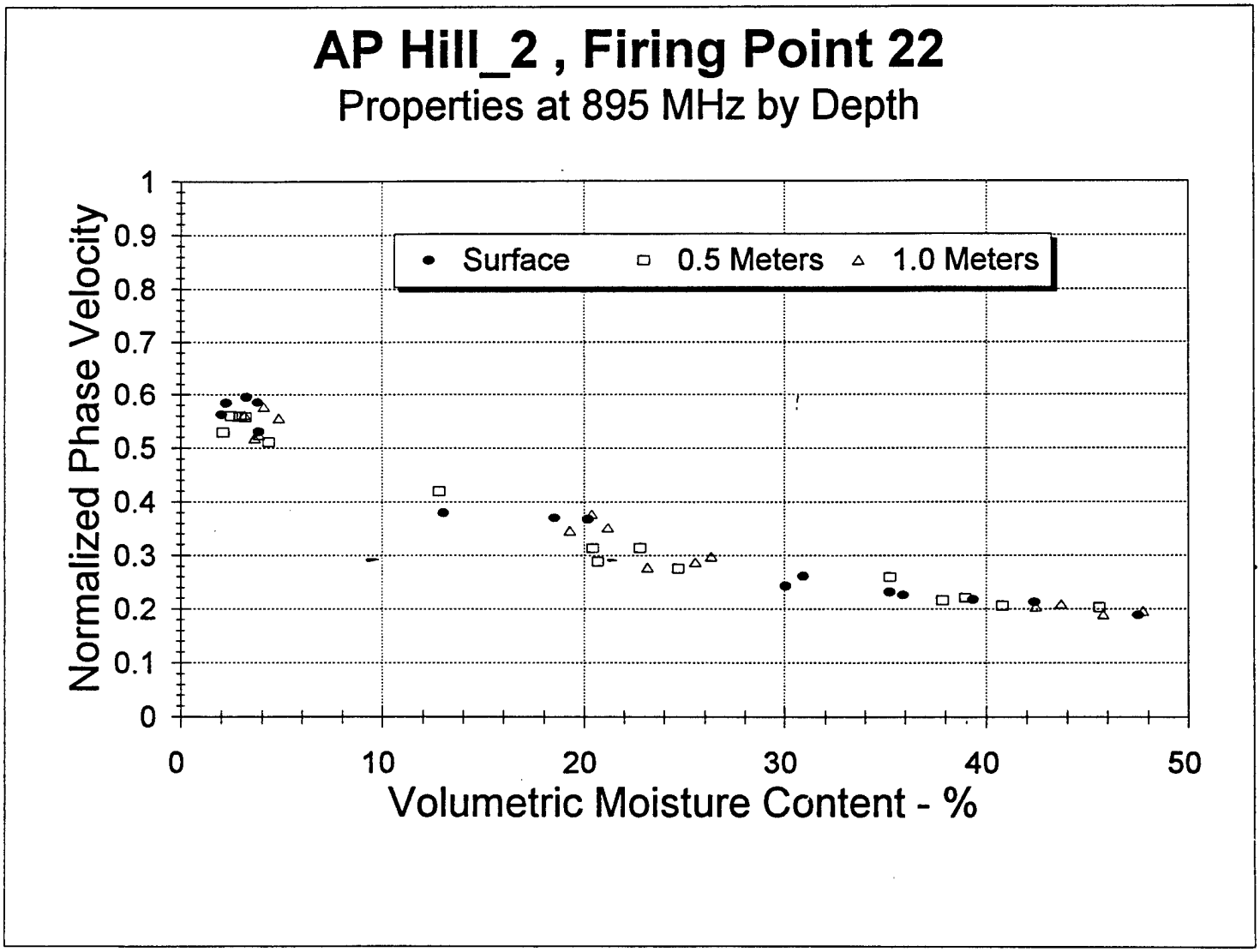


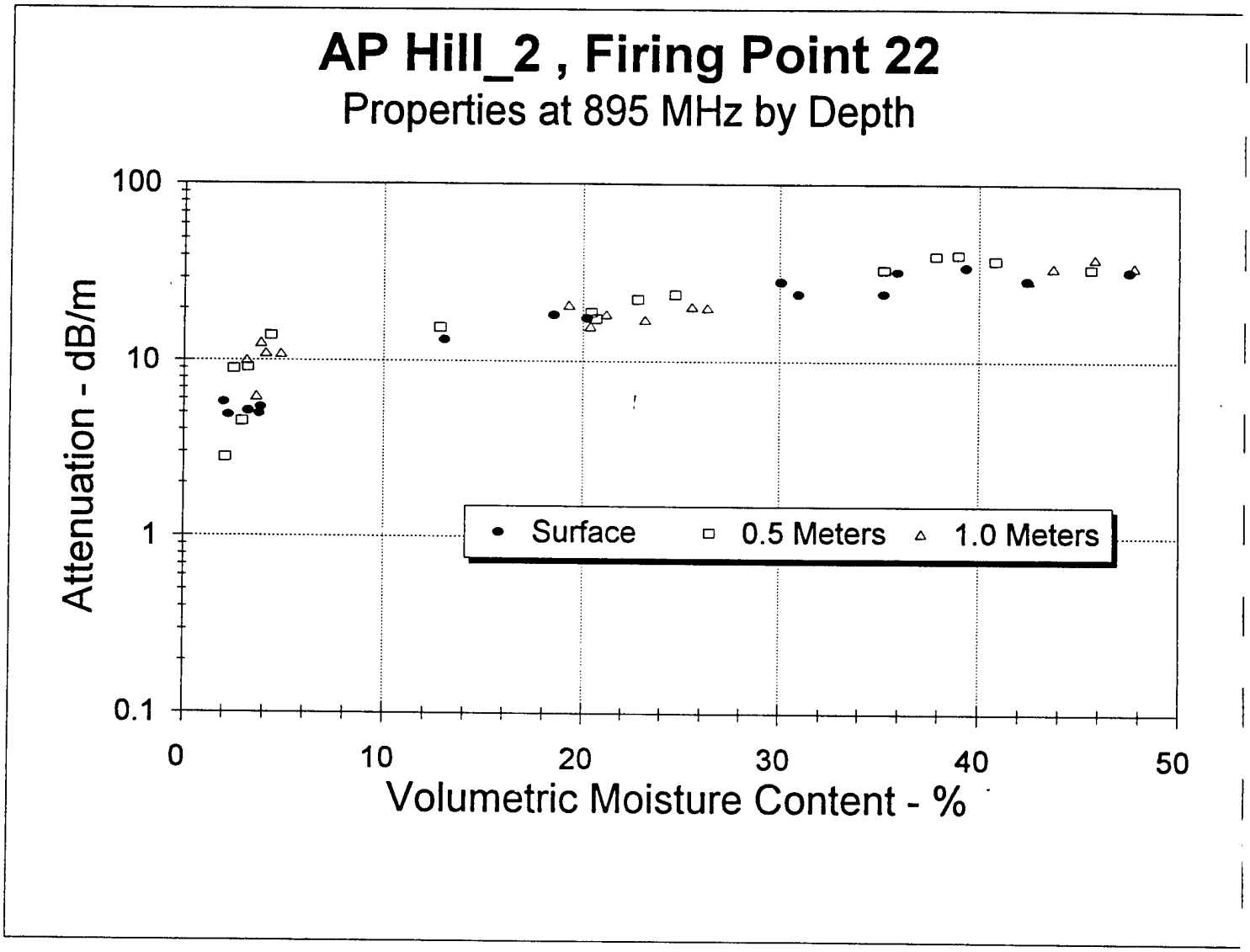

AP Hill_2 , Firing Point 22
Properties at 895 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Re(Dielectric Constant)
Volumetric Moisture Content - %
0
10
20
30
40
50


AP Hill_2 , Firing Point 22
Properties at 895 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Im(Dielectric Constant)
0
10
20
30
40
50
Volumetric Moisture Content - %


AP Hill_2 , Firing Point 22
Properties at 895 MHz by Depth
Surface
0.5 Meters
1.0 Meters
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
Volumetric Moisture Content - %


AP Hill_2 , Firing Point 22
Properties at 895 MHz by Depth
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters


AP Hill_2 , Firing Point 22
Properties at 895 MHz by Depth
Normalized Phase Velocity
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
50


AP Hill_2 , Firing Point 22
Properties at 895 MHz by Depth
Attenuation - dB/m
100
10
1
0.1
0
10
20
30
40
50
Volumetric Moisture Content - %
Surface
0.5 Meters
1.0 Meters

20 August 1996

Data Report

# Dielectric Properties of Soils

## Fort A.P. Hill, VA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## Introduction

This report contains dielectric property measurement results for soils. The original data were collected in the form of the real and imaginary parts of the complex dielectric constant versus frequency. The data collection apparatus was a Hewlet-Packard 8510C Vector Network Analyzer System with an S-Parameter Test Set. Software developed at the U.S. Army Engineer Waterways Experiment Station was used to convert S-parameter measurements at selected frequencies into a complex dielectric constant. The soils were assumed to be nonmagnetic. Other useful electromagnetic properties were calculated from the dielectric constant and frequency, including an equivalent electrical conductivity, the loss tangent, power attenuation, and a normalized phase velocity. The section entitled, "Fundamental Relationships," contains the formulae used to calculate these properties. Additional physical parameters of the soil samples that are included in the report include their dry density, volumetric moisture content, and temperature.

Measurement results and calculated parameters are displayed in three sections. The first includes properties at a selected frequency(ies) and displayed as a function of volumetric moisture content. The intent of presenting data in this way is to demonstrate the experimental observation that the real part of the dielectric constant, as well as the normalized phase velocity are strong functions of volumetric moisture and reasonably independent of soil texture. Other parameters are clearly dependent on soil texture, and, given enough data from several different types of soils, their graphs versus moisture content would show a great deal of scatter. A second set of graphs and tables contain parameters plotted versus frequency for each individual sample tested with the laboratory apparatus. Finally, a third set of graphs contain parameters plotted against frequency for all of the samples. This was done to simply demonstrate that, when viewed as a function of frequency, soil electromagnetic properties are strong functions of moisture and texture.

For additional details on how the data were collected, please contact me at the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, (voice: 601-634-2855, FAX: 601-634-2732, e-mail: curtisj@ex1.wes.army.mil).

## Source of Soil Samples

The laboratory measurements reported, herein, were performed on soils from Fort A.P. Hill, ~~MI~~ VA Near-surface bag samples were collected on 21 March, 1996, by Mr. Jose Llopis, from the Goetechnical Laboratory at the U.S. Army Engineer Waterways Experiment Station. Mr. Llopis' sketches of sample locations are included as the last item in this data report.

Gradation curves of the three soils measured in this study were provided to the Fort Belvoir, Countermine Directorate, Mine Detection Office in May of 1996. These curves and supporting Atterberg limits data indicated little, if any, clay content in the Fort A.P. Hill soils. The absence of swelling clay minerals was confirmed during the collection of electromagnetic property data, as no change in sample volume was observed following the addition of water to the samples.

## Fundamental Relationships

Assuming plane harmonic wave propagation in a lossy, non-magnetic, unbounded medium, the wave amplitude function may be written:

$$e^{i(kx - \omega t)}$$

where

$k$ $= \beta + i\alpha$ $= \omega N/c$

is the complex propagation constant,

$\beta$ is the phase constant,

$\alpha$ is the amplitude attenuation factor,

$\omega$ is the radial frequency,

$N$ is the complex index of refraction,

$c$ is the velocity of light in a vacuum,

$i$ is the symbol designating an imaginary quantity = $\sqrt{-1}$ ,

$x$ is a space coordinate, and

$t$ is time.

Furthermore,

$$N^2 = \epsilon = \epsilon' + \epsilon''$$

where $\epsilon$ is the relative complex dielectric constant, which, along with the electrical conductivity from Ohm's Law, represents the electrical properties of the medium. The interpretation of these properties as used in this study is that the conductivity, $\sigma$ , accounts for current due to free charged particle motion, while the imaginary part of the complex dielectric constant, $\epsilon''$ , accounts for displacement current losses (those due to the electric polarization of the medium). When both conduction and displacement currents are considered, one finds two terms in Ampere's law for current flow that represent losses (or a shift in phase), one containing the electrical conductivity and one containing the imaginary part of the dielectric constant. While these two terms account

for different loss mechanisms, most researchers use only one term or the other to identify losses, with many users preferring to deal with the concept of electrical conductivity. In MKS units, the relationship between the two quantities is taken to be

$$\sigma = \epsilon'' \epsilon_0 \omega$$

where the units of conductivity are mhos/meter (or siemens/meter) and $\epsilon_0$ is the permittivity of free space ($8.85 \times 10^{-12}$ farads/meter).

Squaring the expression for the complex propagation constant, substituting the expression for the square of the complex index of refraction, and equating real and imaginary components, one obtains two algebraic equations that relate the amplitude attenuation factor and phase constant to the complex dielectric constant:

$$\beta^2 - \alpha^2 = \frac{\omega^2}{c^2} \epsilon'$$

and

$$\alpha\beta = \frac{\omega^2 \epsilon''}{2c^2}$$

Solving these equations for the amplitude attenuation factor and for the phase constant results in the following expressions:

$$\alpha = \frac{\omega}{c} \left( \frac{\epsilon'}{2} \left( \sqrt{1 + \left( \frac{\epsilon''}{\epsilon'} \right)^2} - 1 \right) \right)^{1/2}$$

and

$$\beta = \frac{\omega}{c} \left( \frac{\epsilon'}{2} \left( \sqrt{1 + \left( \frac{\epsilon''}{\epsilon'} \right)^2} + 1 \right) \right)^{1/2}$$

The $\epsilon''/\epsilon'$ ratio is also referred to as the loss tangent. Some researchers prefer to work with the electrical conductivity in place of the dielectric loss term.

Plane waves of constant phase will propagate with a velocity

$$v = \frac{\omega}{\beta} = c \left( \frac{\epsilon'}{2} \left( \sqrt{1 + \left( \frac{\epsilon''}{\epsilon'} \right)^2} + 1 \right) \right)^{-1/2}$$

This phase velocity is not necessarily the speed with which the energy of the wave propagates through the

medium. The latter is refered to as the group velocity and can be calculated as the rate of change of radial frequency with respect to the phase constant. However, as long as the phase velocity is relatively constant over the range of frequencies of interest, then there is little difference between phase velocity and group velocity.

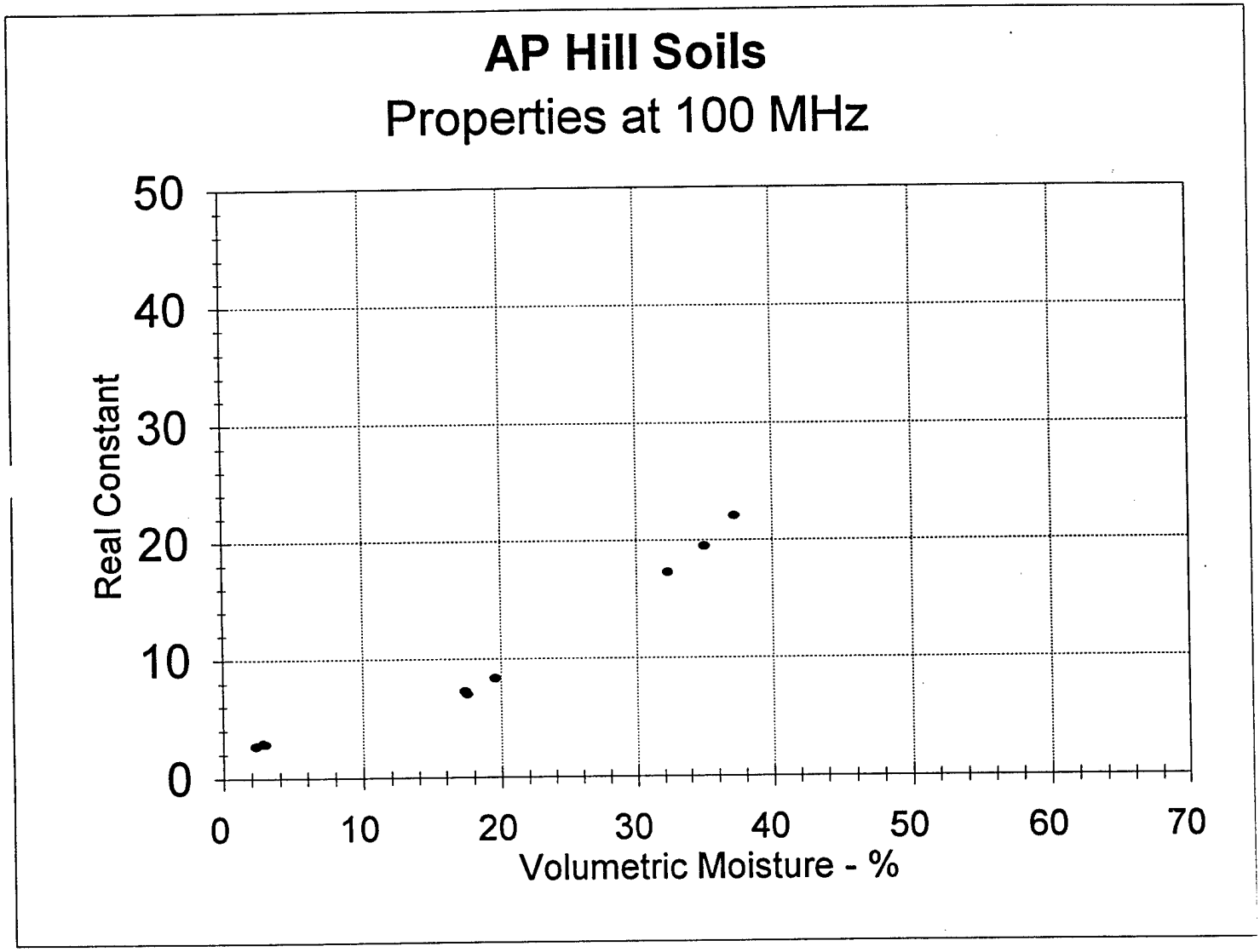
The power intensity of the plane electromagnetic wave decreases exponentially with depth of penetration by the factor, $e^{-2\alpha x}$, or, in one unit of distance traveled, a decrease of $e^{-2\alpha}$. Power attenuation expressed in decibels per meter can then be written as:

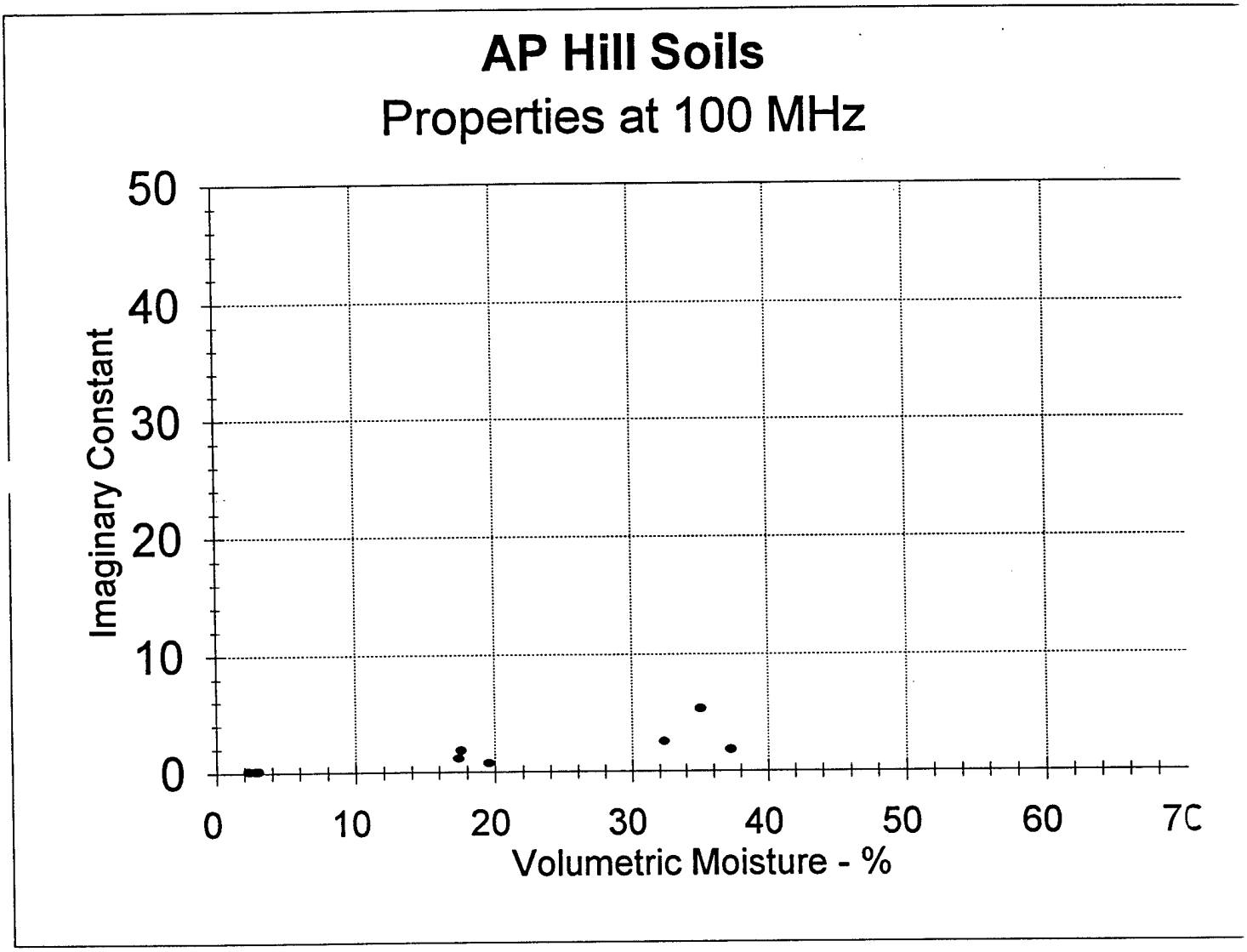
$$PL = -8.6859 \frac{\omega}{c} \left( \frac{\epsilon'}{2} \left( \sqrt{1 + \left( \frac{\epsilon''}{\epsilon'} \right)^2} - 1 \right) \right)^{1/2}$$

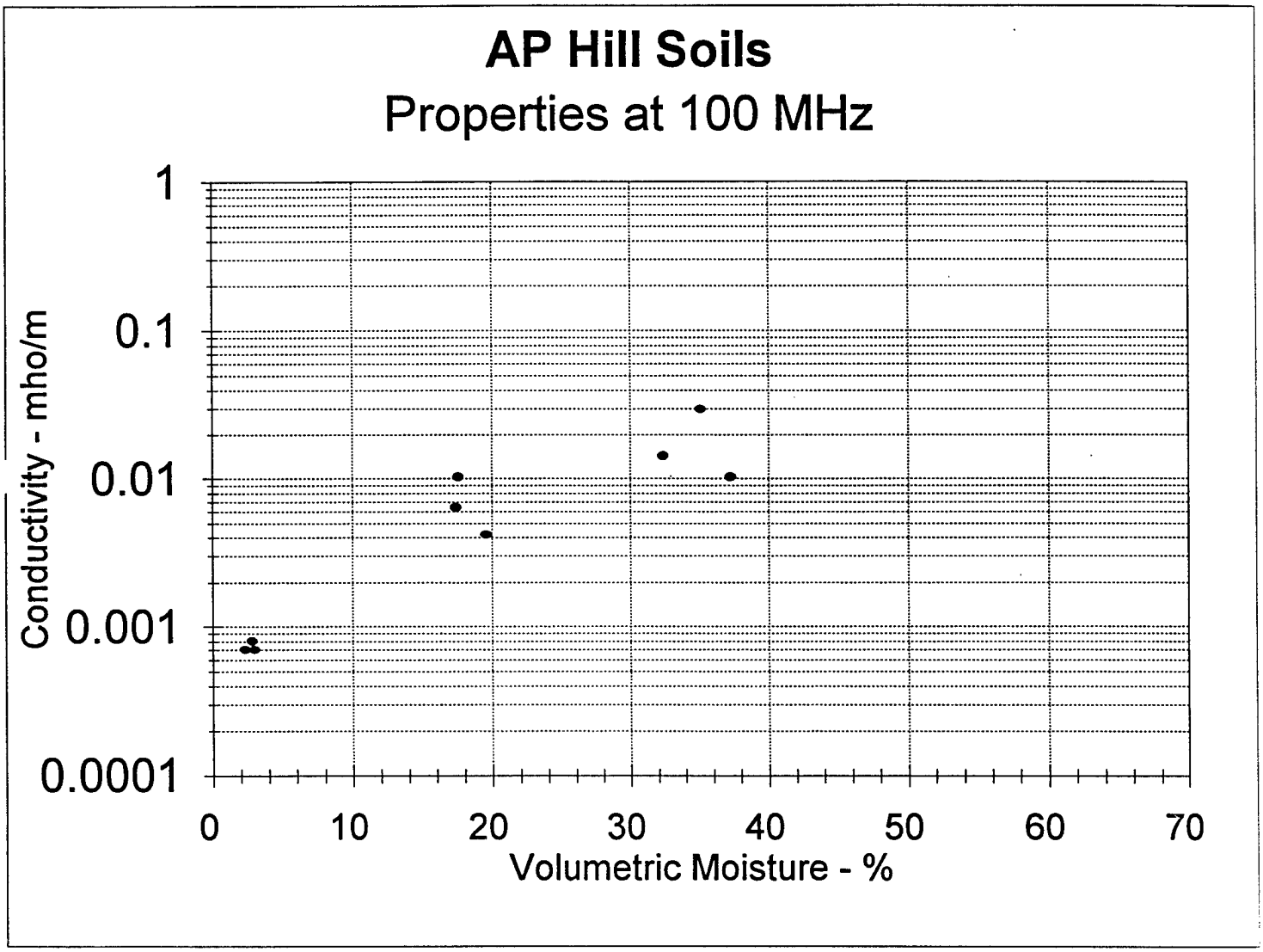
# Fort A.P. Hill
# Properties at 100 Mhz

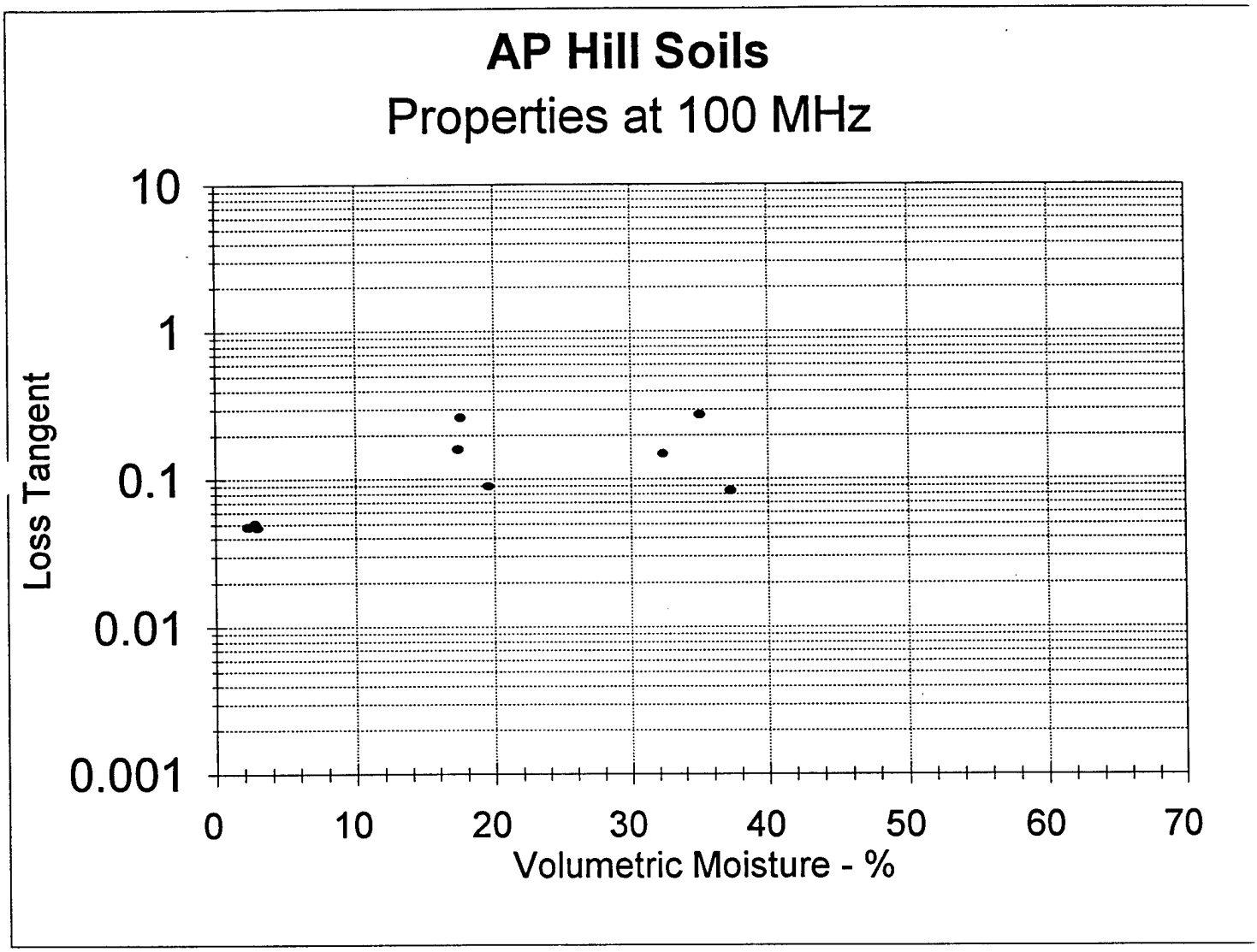
Fort A.P. Hill Soil Properties at 100 MHz

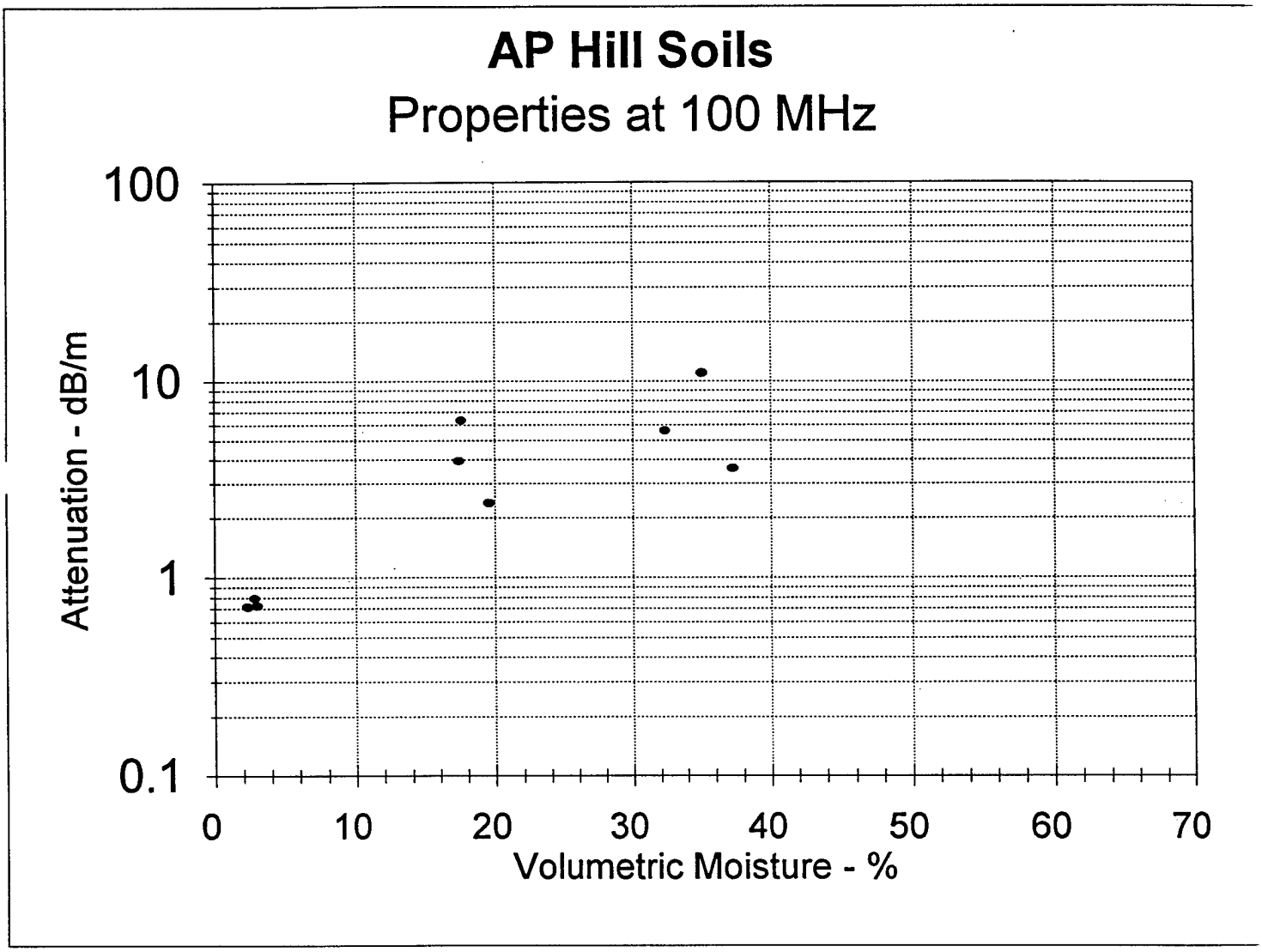
| Vol. Moisture - % | Re(Dielectric) | Im(Dielectric) | Cond. - mho/m | Loss Tangent | Attn. - dB/m | Norm. Velocity | |
|---|---|---|---|---|---|---|---|
| 2.3 | 2.7067 | 0.1293 | 0.0007 | 0.0478 | 0.7144 | 0.6077 | |
| 17.6 | 7.0409 | 1.8532 | 0.0103 | 0.2632 | 6.2993 | 0.3737 | Off Road, dry density = 1.51 g/cc |
| 35.1 | 19.5089 | 5.3602 | 0.0298 | 0.2748 | 10.9376 | 0.2243 | |
| 2.8 | 2.9602 | 0.1488 | 0.0008 | 0.0503 | 0.7866 | 0.581 | |
| 19.6 | 8.347 | 0.7527 | 0.0042 | 0.0902 | 2.3673 | 0.3458 | Dart Road, dry density = 1.47 g/cc |
| 37.3 | 22.0987 | 1.8511 | 0.0103 | 0.0838 | 3.5785 | 0.2125 | |
| 3 | 2.856 | 0.1338 | 0.0007 | 0.0469 | 0.7202 | 0.5916 | |
| 17.4 | 7.2575 | 1.1596 | 0.0064 | 0.1598 | 3.9028 | 0.37 | Top 3", dry density = 1.48 g/cc |
| 32.4 | 17.2805 | 2.5664 | 0.0143 | 0.1485 | 5.6003 | 0.2399 | |

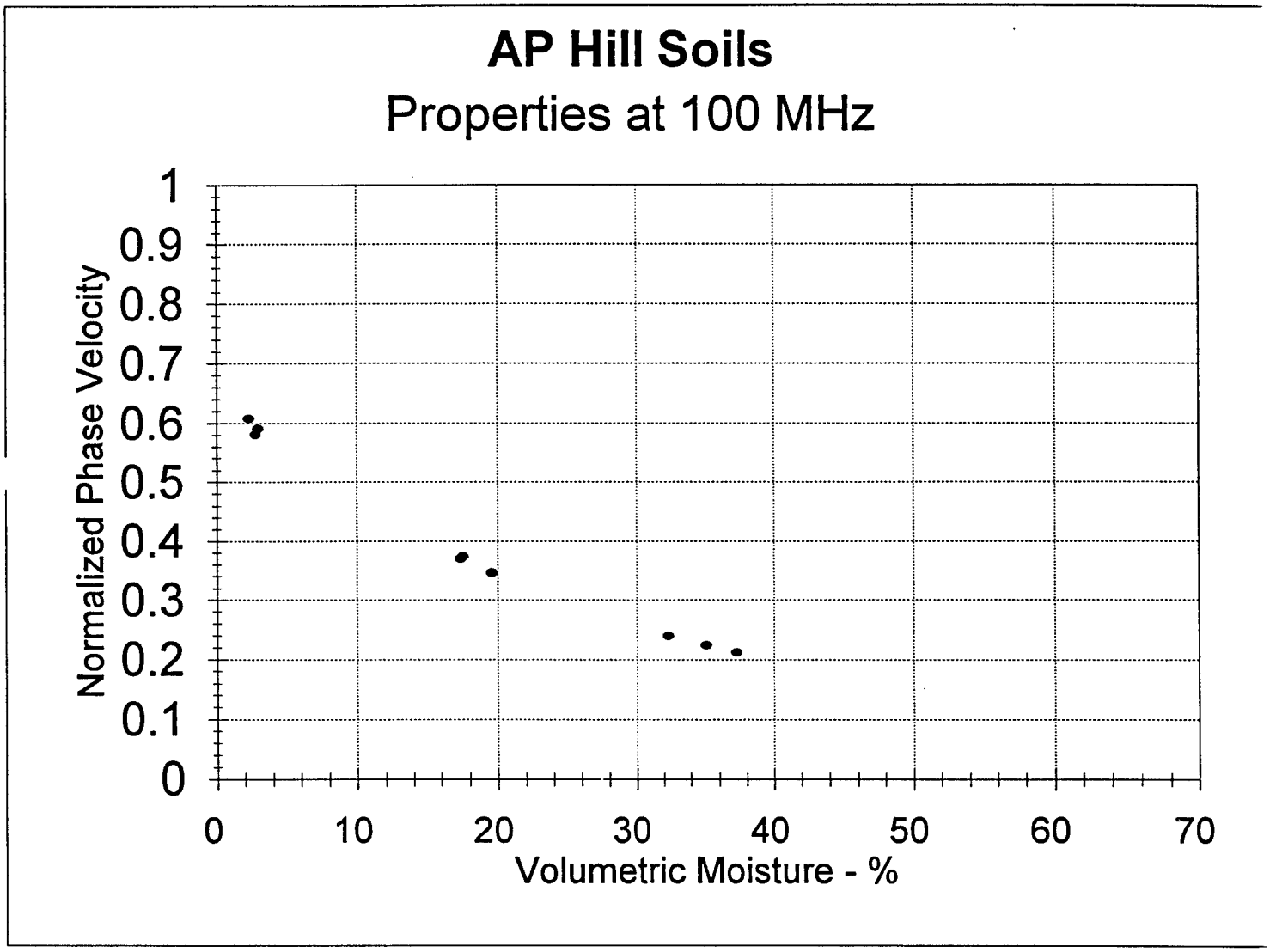

AP Hill Soils
Properties at 100 MHz
Real Constant
50
40
30
20
10
0
0
10
20
30
40
50
60
70
Volumetric Moisture - %


AP Hill Soils
Properties at 100 MHz
Imaginary Constant
50
40
30
20
10
0
0
10
20
30
40
50
60
7C
Volumetric Moisture - %


AP Hill Soils
Properties at 100 MHz
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
70
Volumetric Moisture - %


AP Hill Soils
Properties at 100 MHz
Loss Tangent
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
70
Volumetric Moisture - %


AP Hill Soils
Properties at 100 MHz
100
10
1
0.1
Attenuation - dB/m
0
10
20
30
40
50
60
70
Volumetric Moisture - %


AP Hill Soils
Properties at 100 MHz
Normalized Phase Velocity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
Volumetric Moisture - %

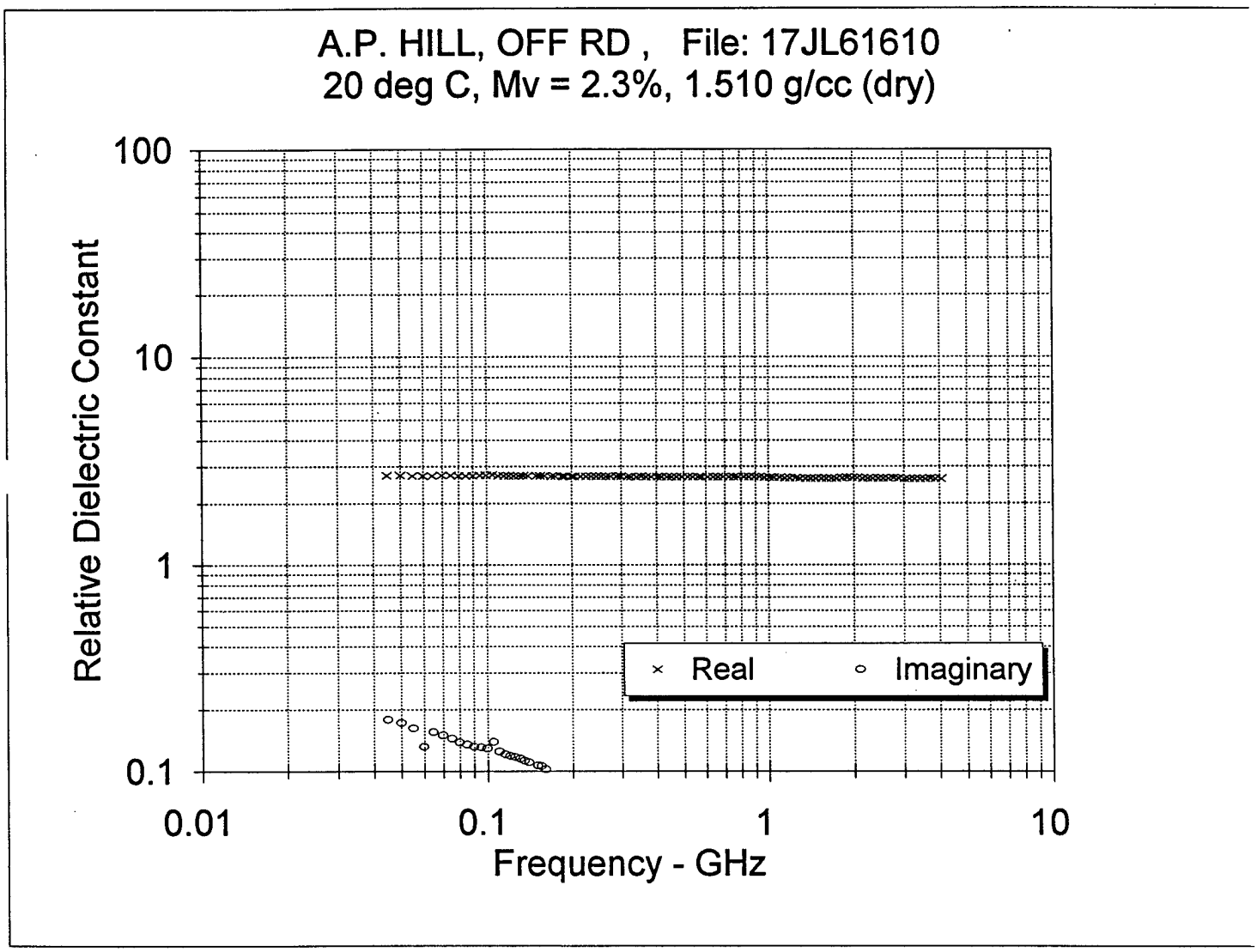
# Fort A.P. Hill
# Individual Sample Results

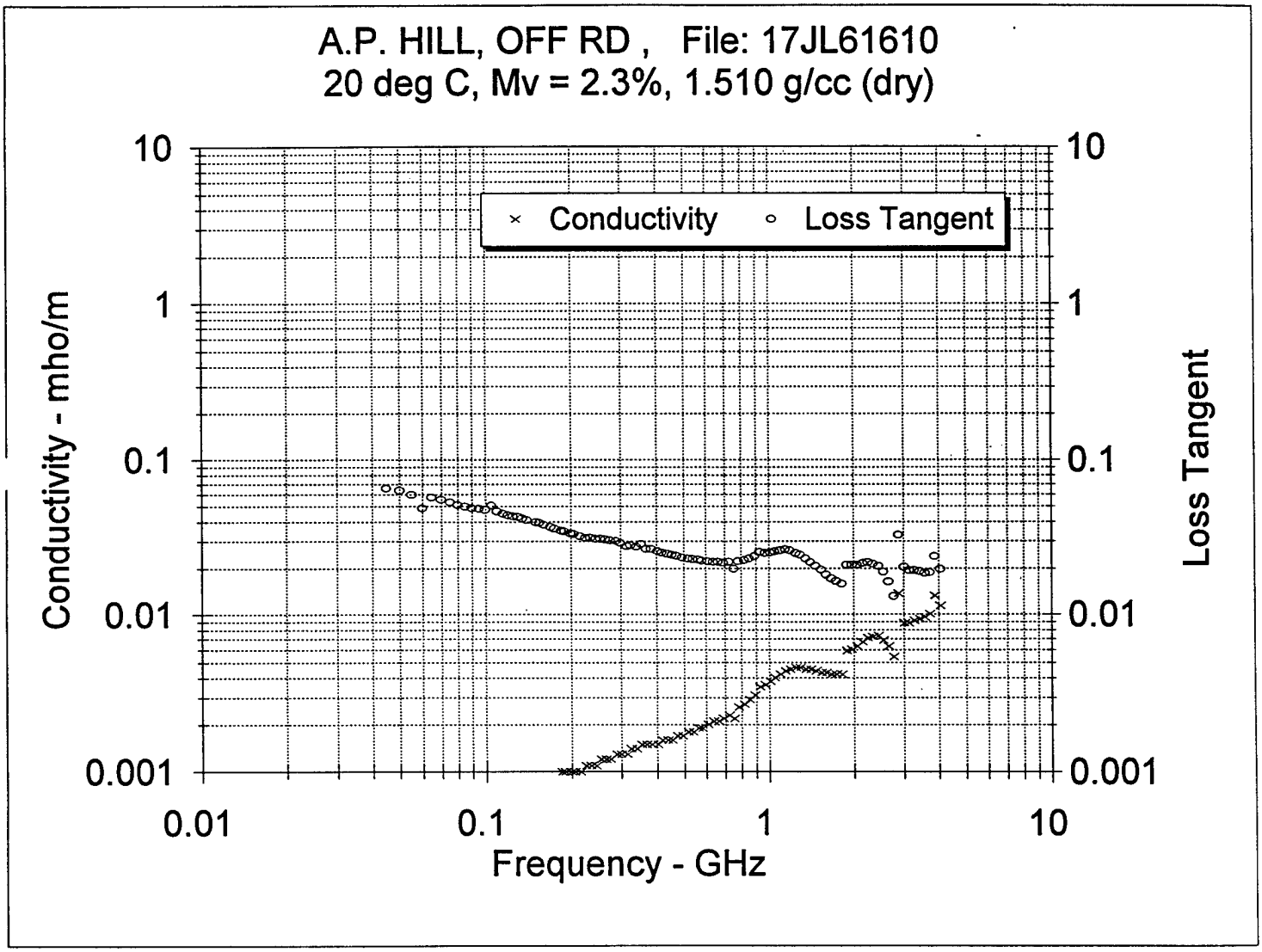
17JL61610
A.P. HILL, OFF RD
9.7
3
2.3
20
1.51

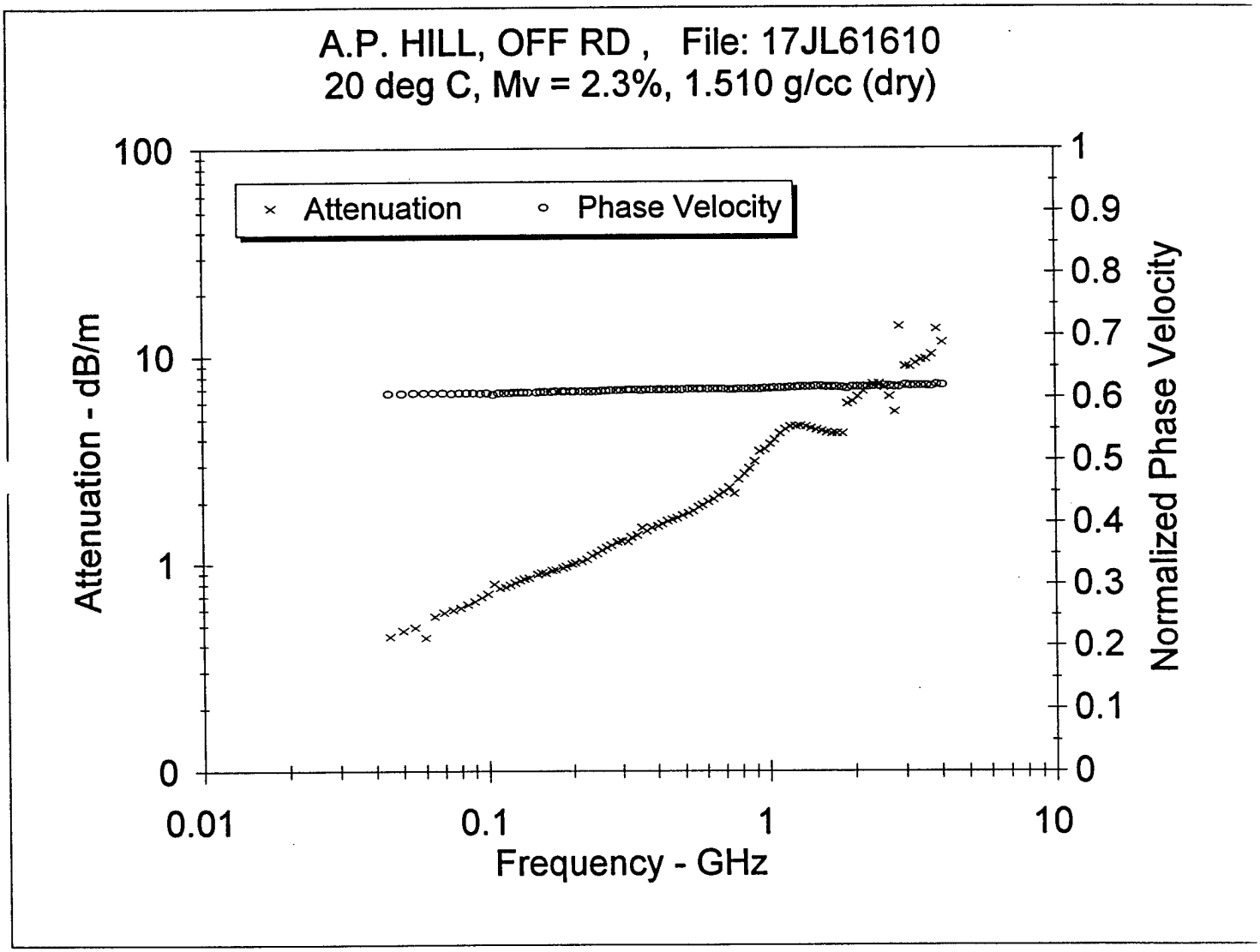
A.P. HILL, OFF RD , File: 17JL61610
20 deg C, Mv = 2.3%, 1.510 g/cc (dry)

| | ε' | ε'' | σ | tan δ | attn | v/c |
|---|---|---|---|---|---|---|
| 0.045 | 2.7065 | 0.1782 | 0.0004 | 0.0659 | 0.4432 | 0.6075 |
| 0.05 | 2.7103 | 0.1717 | 0.0005 | 0.0634 | 0.4742 | 0.6071 |
| 0.055 | 2.7023 | 0.1619 | 0.0005 | 0.0599 | 0.4925 | 0.608 |
| 0.06 | 2.7037 | 0.1322 | 0.0004 | 0.0489 | 0.4385 | 0.608 |
| 0.065 | 2.7051 | 0.1548 | 0.0006 | 0.0572 | 0.5564 | 0.6078 |
| 0.07 | 2.7067 | 0.1498 | 0.0006 | 0.0554 | 0.5796 | 0.6076 |
| 0.075 | 2.7088 | 0.1445 | 0.0006 | 0.0533 | 0.5986 | 0.6074 |
| 0.08 | 2.703 | 0.1382 | 0.0006 | 0.0511 | 0.6117 | 0.608 |
| 0.085 | 2.7056 | 0.135 | 0.0006 | 0.0499 | 0.6345 | 0.6078 |
| 0.09 | 2.7032 | 0.132 | 0.0007 | 0.0488 | 0.657 | 0.608 |
| 0.095 | 2.7083 | 0.1313 | 0.0007 | 0.0485 | 0.6892 | 0.6075 |
| 0.1 | 2.7067 | 0.1293 | 0.0007 | 0.0478 | 0.7144 | 0.6077 |
| 0.105 | 2.7232 | 0.1388 | 0.0008 | 0.051 | 0.8029 | 0.6058 |
| 0.11 | 2.7025 | 0.1256 | 0.0008 | 0.0465 | 0.7642 | 0.6081 |
| 0.115 | 2.7016 | 0.1214 | 0.0008 | 0.045 | 0.7727 | 0.6082 |
| 0.12 | 2.7045 | 0.1193 | 0.0008 | 0.0441 | 0.7918 | 0.6079 |
| 0.125 | 2.7009 | 0.1175 | 0.0008 | 0.0435 | 0.8129 | 0.6083 |
| 0.13 | 2.699 | 0.1154 | 0.0008 | 0.0428 | 0.8303 | 0.6086 |
| 0.135 | 2.6978 | 0.1132 | 0.0009 | 0.042 | 0.8464 | 0.6087 |
| 0.14 | 2.698 | 0.1105 | 0.0009 | 0.0409 | 0.8564 | 0.6087 |
| 0.15 | 2.6951 | 0.1072 | 0.0009 | 0.0398 | 0.8906 | 0.609 |
| 0.155 | 2.6935 | 0.1061 | 0.0009 | 0.0394 | 0.9115 | 0.6092 |
| 0.16 | 2.6925 | 0.1023 | 0.0009 | 0.038 | 0.907 | 0.6093 |
| 0.17 | 2.6906 | 0.0988 | 0.0009 | 0.0367 | 0.9317 | 0.6095 |
| 0.175 | 2.6887 | 0.0967 | 0.0009 | 0.036 | 0.9388 | 0.6098 |
| 0.185 | 2.6867 | 0.0937 | 0.001 | 0.0349 | 0.9619 | 0.61 |
| 0.19 | 2.6856 | 0.0929 | 0.001 | 0.0346 | 0.9797 | 0.6101 |
| 0.2 | 2.6839 | 0.0901 | 0.001 | 0.0336 | 1.0008 | 0.6103 |
| 0.205 | 2.6824 | 0.089 | 0.001 | 0.0332 | 1.0135 | 0.6105 |
| 0.215 | 2.6805 | 0.0864 | 0.001 | 0.0322 | 1.0319 | 0.6107 |
| 0.225 | 2.6793 | 0.0846 | 0.0011 | 0.0316 | 1.058 | 0.6108 |
| 0.235 | 2.6763 | 0.0844 | 0.0011 | 0.0315 | 1.1022 | 0.6112 |
| 0.245 | 2.6763 | 0.0829 | 0.0011 | 0.031 | 1.1297 | 0.6112 |
| 0.255 | 2.6735 | 0.0825 | 0.0012 | 0.0309 | 1.1705 | 0.6115 |
| 0.265 | 2.67 | 0.0819 | 0.0012 | 0.0307 | 1.2077 | 0.6119 |
| 0.275 | 2.6683 | 0.0809 | 0.0012 | 0.0303 | 1.2386 | 0.6121 |
| 0.29 | 2.6655 | 0.0794 | 0.0013 | 0.0298 | 1.2825 | 0.6124 |
| 0.3 | 2.6647 | 0.0775 | 0.0013 | 0.0291 | 1.2957 | 0.6125 |
| 0.315 | 2.6571 | 0.0733 | 0.0013 | 0.0276 | 1.2883 | 0.6134 |
| 0.325 | 2.6627 | 0.0747 | 0.0014 | 0.0281 | 1.3536 | 0.6128 |
| 0.34 | 2.661 | 0.073 | 0.0014 | 0.0274 | 1.3843 | 0.613 |
| 0.355 | 2.6653 | 0.0762 | 0.0015 | 0.0286 | 1.5068 | 0.6125 |
| 0.37 | 2.6598 | 0.0705 | 0.0015 | 0.0265 | 1.4554 | 0.6131 |
| 0.385 | 2.6604 | 0.0704 | 0.0015 | 0.0265 | 1.5114 | 0.613 |
| 0.405 | 2.6599 | 0.068 | 0.0015 | 0.0256 | 1.5357 | 0.6131 |
| 0.42 | 2.6602 | 0.067 | 0.0016 | 0.0252 | 1.5701 | 0.6131 |
| 0.44 | 2.6592 | 0.0658 | 0.0016 | 0.0248 | 1.6154 | 0.6132 |
| 0.455 | 2.659 | 0.0648 | 0.0016 | 0.0244 | 1.6457 | 0.6132 |
| 0.475 | 2.6581 | 0.0634 | 0.0017 | 0.0239 | 1.68 | 0.6133 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.495 | 2.657 | 0.0626 | 0.0017 | 0.0235 | 1.728 | 0.6134 |
| 0.52 | 2.6557 | 0.0612 | 0.0018 | 0.023 | 1.775 | 0.6136 |
| 0.54 | 2.6543 | 0.0604 | 0.0018 | 0.0228 | 1.8223 | 0.6138 |
| 0.565 | 2.6531 | 0.0599 | 0.0019 | 0.0226 | 1.8893 | 0.6139 |
| 0.585 | 2.6528 | 0.0591 | 0.0019 | 0.0223 | 1.9314 | 0.6139 |
| 0.61 | 2.653 | 0.059 | 0.002 | 0.0222 | 2.0099 | 0.6139 |
| 0.64 | 2.6543 | 0.0581 | 0.0021 | 0.0219 | 2.0761 | 0.6138 |
| 0.665 | 2.6555 | 0.058 | 0.0021 | 0.0218 | 2.1533 | 0.6136 |
| 0.695 | 2.6559 | 0.0573 | 0.0022 | 0.0216 | 2.2224 | 0.6136 |
| 0.725 | 2.6562 | 0.0579 | 0.0023 | 0.0218 | 2.3425 | 0.6135 |
| 0.755 | 2.6606 | 0.0523 | 0.0022 | 0.0197 | 2.2027 | 0.613 |
| 0.785 | 2.6542 | 0.0587 | 0.0026 | 0.0221 | 2.5732 | 0.6138 |
| 0.82 | 2.6531 | 0.0596 | 0.0027 | 0.0225 | 2.728 | 0.6139 |
| 0.855 | 2.6525 | 0.0606 | 0.0029 | 0.0229 | 2.8954 | 0.614 |
| 0.895 | 2.6533 | 0.0629 | 0.0031 | 0.0237 | 3.1414 | 0.6139 |
| 0.93 | 2.6539 | 0.0671 | 0.0035 | 0.0253 | 3.4818 | 0.6138 |
| 0.97 | 2.6456 | 0.066 | 0.0036 | 0.025 | 3.5814 | 0.6148 |
| 1.015 | 2.645 | 0.0668 | 0.0038 | 0.0252 | 3.7901 | 0.6148 |
| 1.055 | 2.6427 | 0.0675 | 0.004 | 0.0255 | 3.9814 | 0.6151 |
| 1.1 | 2.6395 | 0.0688 | 0.0042 | 0.026 | 4.2339 | 0.6155 |
| 1.15 | 2.6344 | 0.0693 | 0.0044 | 0.0263 | 4.4657 | 0.6161 |
| 1.195 | 2.6301 | 0.0683 | 0.0045 | 0.026 | 4.5781 | 0.6166 |
| 1.25 | 2.625 | 0.0657 | 0.0046 | 0.025 | 4.6088 | 0.6172 |
| 1.3 | 2.6219 | 0.0634 | 0.0046 | 0.0242 | 4.6262 | 0.6175 |
| 1.36 | 2.6197 | 0.0601 | 0.0045 | 0.023 | 4.5963 | 0.6178 |
| 1.415 | 2.6186 | 0.0568 | 0.0045 | 0.0217 | 4.5197 | 0.6179 |
| 1.475 | 2.6171 | 0.0536 | 0.0044 | 0.0205 | 4.4409 | 0.6181 |
| 1.54 | 2.6171 | 0.0506 | 0.0043 | 0.0194 | 4.3851 | 0.6181 |
| 1.605 | 2.6186 | 0.0478 | 0.0043 | 0.0182 | 4.3104 | 0.6179 |
| 1.675 | 2.6202 | 0.045 | 0.0042 | 0.0172 | 4.2391 | 0.6178 |
| 1.745 | 2.6228 | 0.0432 | 0.0042 | 0.0165 | 4.2381 | 0.6175 |
| 1.82 | 2.6274 | 0.0415 | 0.0042 | 0.0158 | 4.2368 | 0.6169 |
| 1.9 | 2.6475 | 0.0557 | 0.0059 | 0.021 | 5.913 | 0.6145 |
| 1.98 | 2.6233 | 0.0545 | 0.006 | 0.0208 | 6.0624 | 0.6174 |
| 2.065 | 2.6241 | 0.055 | 0.0063 | 0.021 | 6.376 | 0.6173 |
| 2.155 | 2.6212 | 0.0561 | 0.0067 | 0.0214 | 6.7918 | 0.6176 |
| 2.25 | 2.6187 | 0.0567 | 0.0071 | 0.0217 | 7.174 | 0.6179 |
| 2.345 | 2.6155 | 0.0554 | 0.0072 | 0.0212 | 7.3099 | 0.6183 |
| 2.445 | 2.6126 | 0.0536 | 0.0073 | 0.0205 | 7.3783 | 0.6186 |
| 2.55 | 2.6103 | 0.049 | 0.0069 | 0.0188 | 7.0297 | 0.6189 |
| 2.66 | 2.6123 | 0.0427 | 0.0063 | 0.0164 | 6.399 | 0.6187 |
| 2.775 | 2.6232 | 0.0347 | 0.0054 | 0.0132 | 5.4067 | 0.6174 |
| 2.89 | 2.6174 | 0.0856 | 0.0137 | 0.0327 | 13.8999 | 0.618 |
| 3.015 | 2.6046 | 0.0528 | 0.0088 | 0.0203 | 8.9695 | 0.6196 |
| 3.145 | 2.6087 | 0.0504 | 0.0088 | 0.0193 | 8.92 | 0.6191 |
| 3.28 | 2.6091 | 0.0504 | 0.0092 | 0.0193 | 9.3039 | 0.6191 |
| 3.42 | 2.6085 | 0.0497 | 0.0094 | 0.019 | 9.5656 | 0.6191 |
| 3.57 | 2.6094 | 0.0482 | 0.0096 | 0.0185 | 9.6976 | 0.619 |
| 3.72 | 2.6139 | 0.0486 | 0.0101 | 0.0186 | 10.1792 | 0.6185 |
| 3.88 | 2.598 | 0.0616 | 0.0133 | 0.0237 | 13.4875 | 0.6204 |
| 4.045 | 2.6024 | 0.0509 | 0.0114 | 0.0196 | 11.6081 | 0.6199 |


A.P. HILL, OFF RD , File: 17JL61610
20 deg C, Mv = 2.3%, 1.510 g/cc (dry)
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz
Real
Imaginary


A.P. HILL, OFF RD , File: 17JL61610
20 deg C, Mv = 2.3%, 1.510 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
10
1
0.1
0.01
0.001
0.01
0.1
1
10

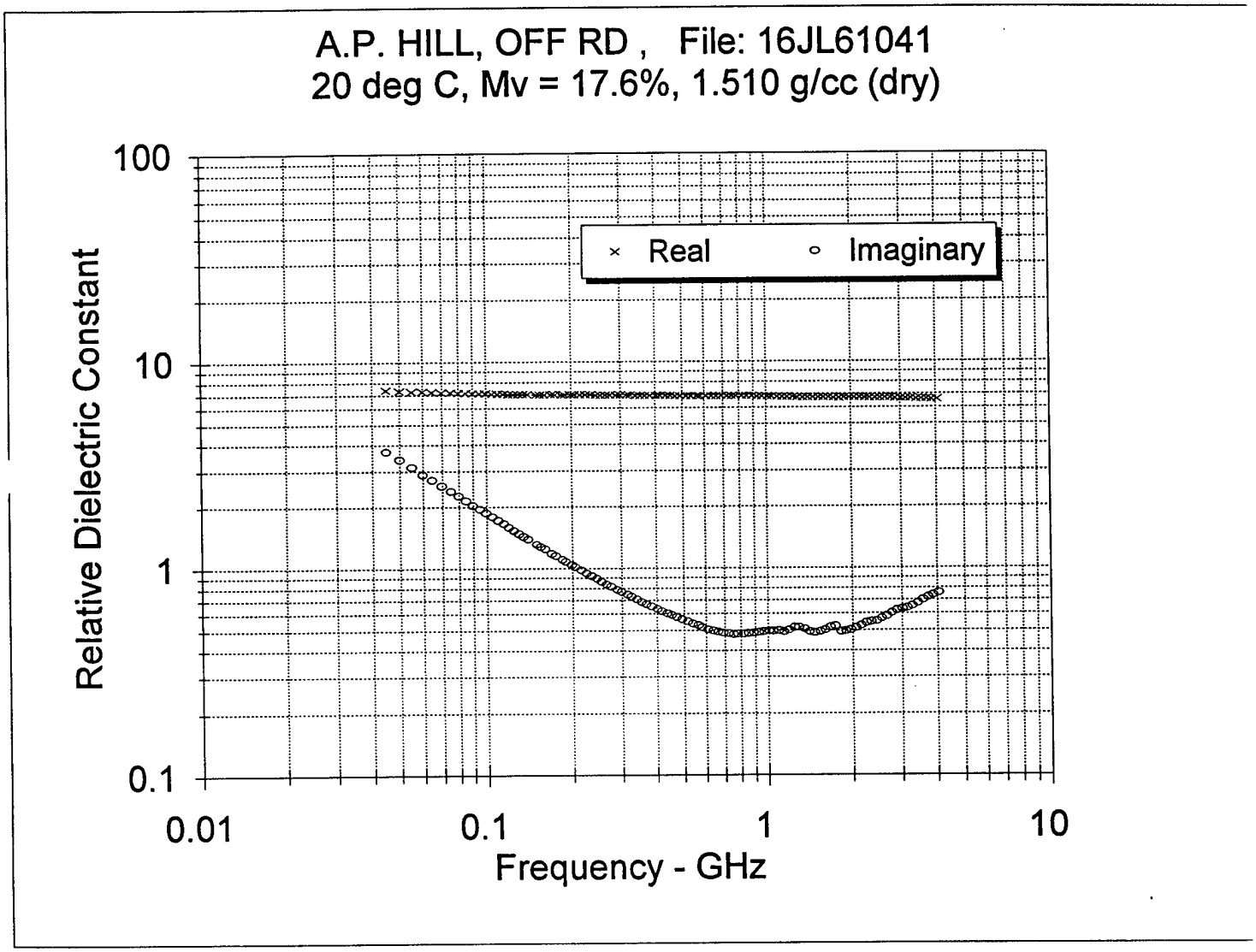

A.P. HILL, OFF RD , File: 17JL61610
20 deg C, Mv = 2.3%, 1.510 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
100
10
1
0
0.01
0.1
1
10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

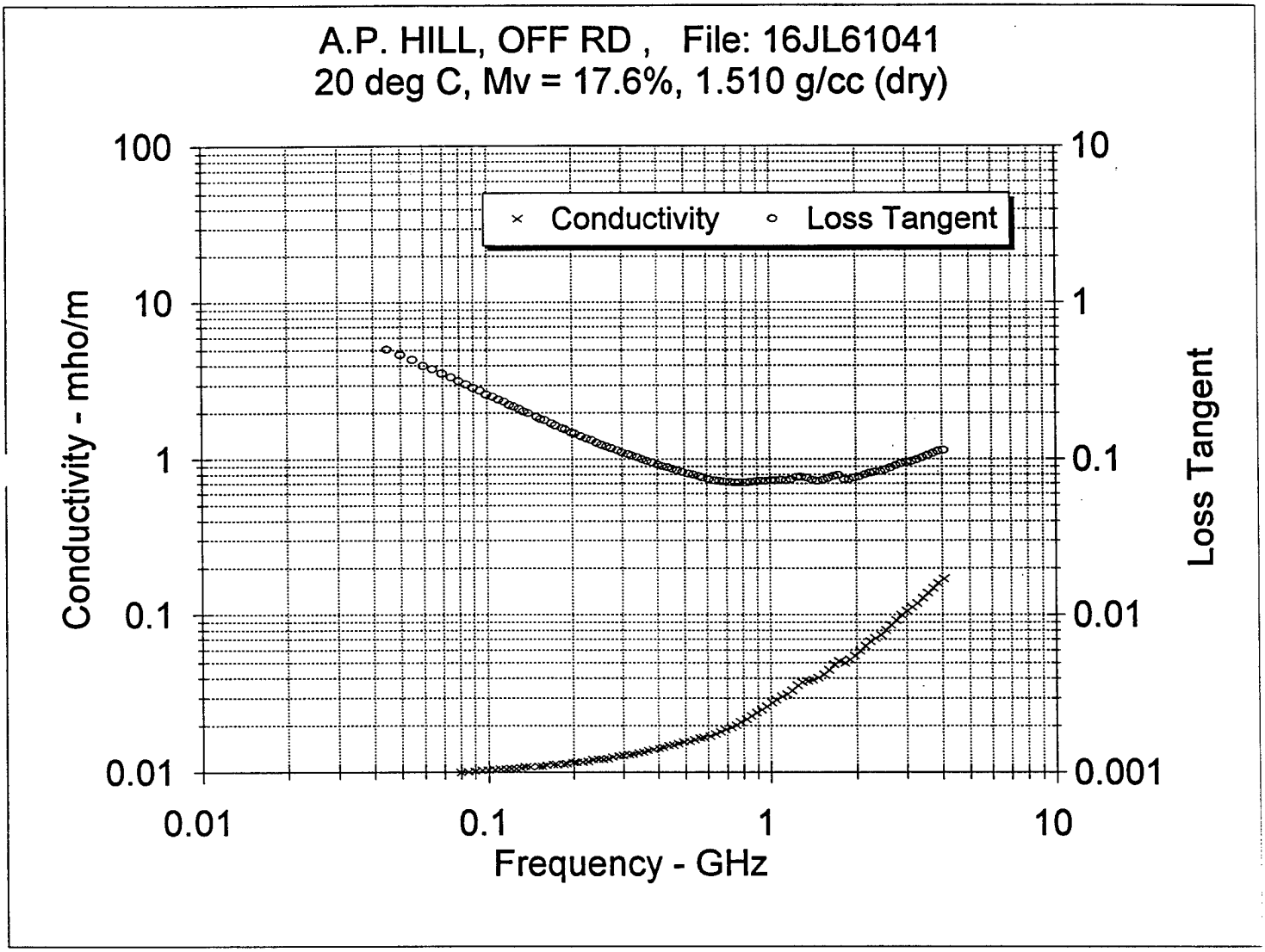
16JL61041
A.P. HILL, OFF RD
9.7
3
17.6
20
1.51

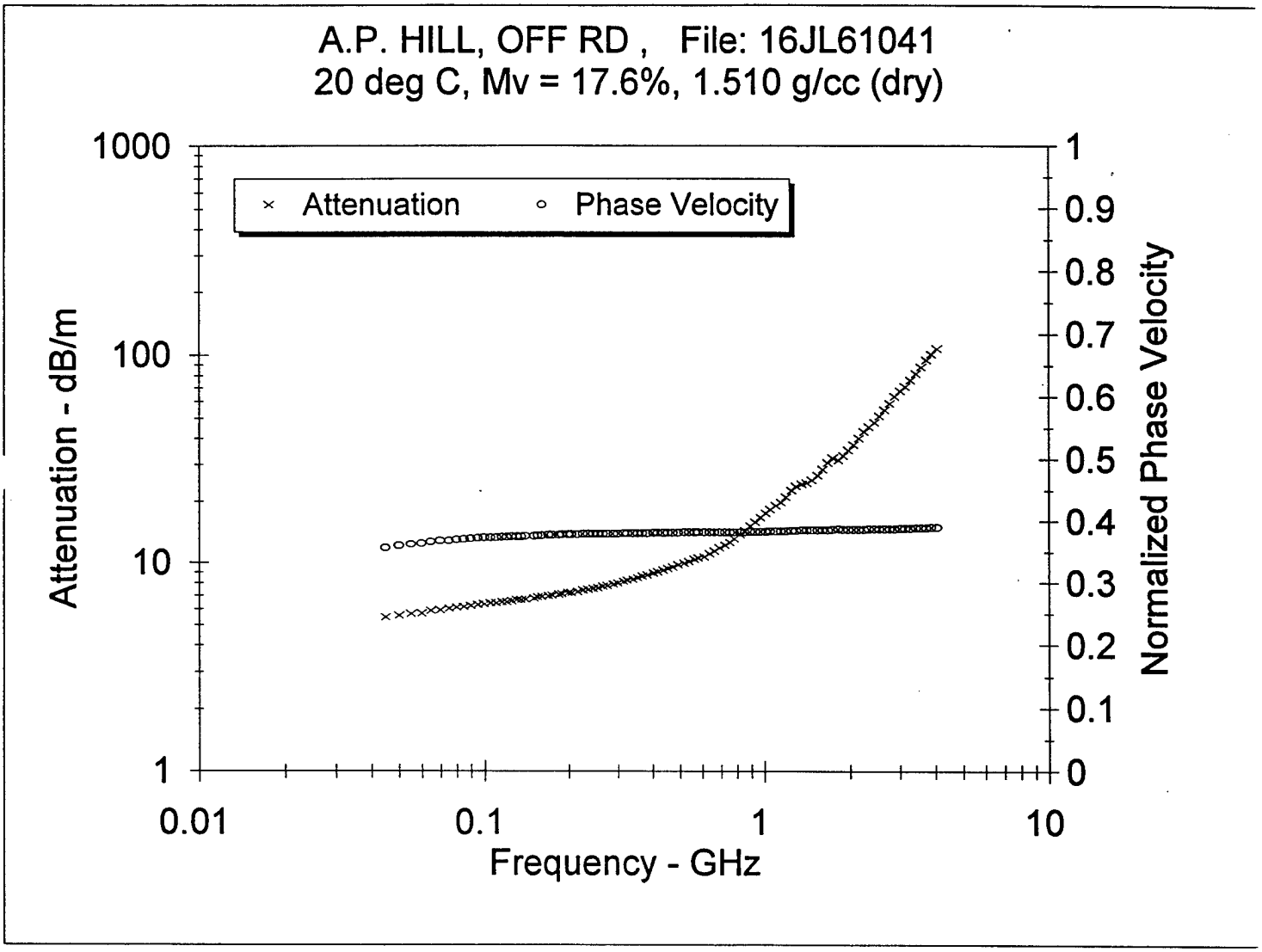
A.P. HILL, OFF RD , File: 16JL61041
20 deg C, Mv = 17.6%, 1.510 g/cc (dry)

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.045 | 7.3357 | 3.7083 | 0.0093 | 0.5055 | 5.4426 | 0.3586 |
| 0.05 | 7.278 | 3.3927 | 0.0094 | 0.4662 | 5.5771 | 0.3615 |
| 0.055 | 7.2321 | 3.1215 | 0.0095 | 0.4316 | 5.6816 | 0.3638 |
| 0.06 | 7.2322 | 2.8667 | 0.0096 | 0.3964 | 5.7104 | 0.365 |
| 0.065 | 7.1688 | 2.6993 | 0.0098 | 0.3765 | 5.8609 | 0.3672 |
| 0.07 | 7.1432 | 2.5282 | 0.0098 | 0.3539 | 5.9334 | 0.3686 |
| 0.075 | 7.1205 | 2.3823 | 0.0099 | 0.3346 | 6.0091 | 0.3698 |
| 0.08 | 7.0965 | 2.2539 | 0.01 | 0.3176 | 6.0822 | 0.3708 |
| 0.085 | 7.0761 | 2.1349 | 0.0101 | 0.3017 | 6.1369 | 0.3718 |
| 0.09 | 7.0643 | 2.0308 | 0.0102 | 0.2875 | 6.1925 | 0.3725 |
| 0.095 | 7.0565 | 1.9418 | 0.0103 | 0.2752 | 6.2586 | 0.373 |
| 0.1 | 7.0409 | 1.8532 | 0.0103 | 0.2632 | 6.2993 | 0.3737 |
| 0.105 | 7.0337 | 1.78 | 0.0104 | 0.2531 | 6.3599 | 0.3741 |
| 0.11 | 7.0196 | 1.709 | 0.0105 | 0.2435 | 6.4072 | 0.3747 |
| 0.115 | 7.0087 | 1.6453 | 0.0105 | 0.2348 | 6.4571 | 0.3752 |
| 0.12 | 6.9991 | 1.5814 | 0.0106 | 0.2259 | 6.4838 | 0.3756 |
| 0.125 | 6.9924 | 1.5303 | 0.0106 | 0.2188 | 6.5411 | 0.376 |
| 0.13 | 6.9839 | 1.4813 | 0.0107 | 0.2121 | 6.5915 | 0.3763 |
| 0.135 | 6.9766 | 1.4326 | 0.0108 | 0.2053 | 6.6255 | 0.3766 |
| 0.14 | 6.9732 | 1.3906 | 0.0108 | 0.1994 | 6.6729 | 0.3768 |
| 0.15 | 6.9604 | 1.3117 | 0.0109 | 0.1885 | 6.7538 | 0.3774 |
| 0.155 | 6.9558 | 1.2775 | 0.011 | 0.1837 | 6.8007 | 0.3776 |
| 0.16 | 6.9489 | 1.2438 | 0.0111 | 0.179 | 6.8399 | 0.3779 |
| 0.17 | 6.9397 | 1.183 | 0.0112 | 0.1705 | 6.9188 | 0.3782 |
| 0.175 | 6.9345 | 1.1545 | 0.0112 | 0.1665 | 6.9547 | 0.3784 |
| 0.185 | 6.9251 | 1.1022 | 0.0113 | 0.1592 | 7.026 | 0.3788 |
| 0.19 | 6.9218 | 1.0791 | 0.0114 | 0.1559 | 7.0671 | 0.379 |
| 0.2 | 6.9166 | 1.0367 | 0.0115 | 0.1499 | 7.1509 | 0.3792 |
| 0.205 | 6.9128 | 1.0159 | 0.0116 | 0.147 | 7.1857 | 0.3793 |
| 0.215 | 6.9068 | 0.9784 | 0.0117 | 0.1417 | 7.2625 | 0.3796 |
| 0.225 | 6.9014 | 0.9462 | 0.0118 | 0.1371 | 7.3539 | 0.3798 |
| 0.235 | 6.8959 | 0.9163 | 0.012 | 0.1329 | 7.4422 | 0.38 |
| 0.245 | 6.8907 | 0.8877 | 0.0121 | 0.1288 | 7.5207 | 0.3802 |
| 0.255 | 6.8848 | 0.8591 | 0.0122 | 0.1248 | 7.5795 | 0.3804 |
| 0.265 | 6.88 | 0.8364 | 0.0123 | 0.1216 | 7.6722 | 0.3805 |
| 0.275 | 6.8748 | 0.8151 | 0.0125 | 0.1186 | 7.7624 | 0.3807 |
| 0.29 | 6.8704 | 0.7861 | 0.0127 | 0.1144 | 7.8982 | 0.3809 |
| 0.3 | 6.8649 | 0.7661 | 0.0128 | 0.1116 | 7.9663 | 0.3811 |
| 0.315 | 6.8597 | 0.7425 | 0.013 | 0.1082 | 8.1103 | 0.3813 |
| 0.325 | 6.858 | 0.7272 | 0.0131 | 0.106 | 8.1974 | 0.3813 |
| 0.34 | 6.852 | 0.705 | 0.0133 | 0.1029 | 8.3184 | 0.3815 |
| 0.355 | 6.8478 | 0.6863 | 0.0135 | 0.1002 | 8.4579 | 0.3817 |
| 0.37 | 6.8435 | 0.6686 | 0.0138 | 0.0977 | 8.5909 | 0.3818 |
| 0.385 | 6.8395 | 0.6525 | 0.014 | 0.0954 | 8.7271 | 0.3819 |
| 0.405 | 6.8344 | 0.6326 | 0.0142 | 0.0926 | 8.9053 | 0.3821 |
| 0.42 | 6.831 | 0.6188 | 0.0145 | 0.0906 | 9.0357 | 0.3822 |
| 0.44 | 6.8255 | 0.6029 | 0.0148 | 0.0883 | 9.2263 | 0.3824 |
| 0.455 | 6.8226 | 0.5911 | 0.015 | 0.0866 | 9.3577 | 0.3825 |
| 0.475 | 6.8184 | 0.5775 | 0.0153 | 0.0847 | 9.5475 | 0.3826 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.495 | 6.8144 | 0.565 | 0.0156 | 0.0829 | 9.7358 | 0.3827 |
| 0.52 | 6.8101 | 0.551 | 0.0159 | 0.0809 | 9.9778 | 0.3829 |
| 0.54 | 6.8068 | 0.5404 | 0.0162 | 0.0794 | 10.166 | 0.383 |
| 0.565 | 6.8017 | 0.5282 | 0.0166 | 0.0777 | 10.4012 | 0.3831 |
| 0.585 | 6.7974 | 0.5176 | 0.0168 | 0.0761 | 10.5553 | 0.3833 |
| 0.61 | 6.8002 | 0.5035 | 0.0171 | 0.074 | 10.7056 | 0.3832 |
| 0.64 | 6.8023 | 0.4968 | 0.0177 | 0.073 | 11.0821 | 0.3832 |
| 0.665 | 6.802 | 0.4922 | 0.0182 | 0.0724 | 11.4072 | 0.3832 |
| 0.695 | 6.8013 | 0.487 | 0.0188 | 0.0716 | 11.7973 | 0.3832 |
| 0.725 | 6.7999 | 0.4833 | 0.0195 | 0.0711 | 12.2137 | 0.3832 |
| 0.755 | 6.7989 | 0.4787 | 0.0201 | 0.0704 | 12.5993 | 0.3833 |
| 0.785 | 6.7984 | 0.4802 | 0.021 | 0.0706 | 13.1421 | 0.3833 |
| 0.82 | 6.7963 | 0.4805 | 0.0219 | 0.0707 | 13.7378 | 0.3833 |
| 0.855 | 6.7927 | 0.4828 | 0.023 | 0.0711 | 14.3958 | 0.3834 |
| 0.895 | 6.7867 | 0.4862 | 0.0242 | 0.0716 | 15.1828 | 0.3836 |
| 0.93 | 6.7799 | 0.488 | 0.0252 | 0.072 | 15.8429 | 0.3838 |
| 0.97 | 6.7737 | 0.4905 | 0.0265 | 0.0724 | 16.6186 | 0.384 |
| 1.015 | 6.7648 | 0.493 | 0.0278 | 0.0729 | 17.4892 | 0.3842 |
| 1.055 | 6.7576 | 0.4943 | 0.029 | 0.0732 | 18.2364 | 0.3844 |
| 1.1 | 6.7492 | 0.4956 | 0.0303 | 0.0734 | 19.0745 | 0.3847 |
| 1.15 | 6.7416 | 0.4915 | 0.0314 | 0.0729 | 19.7862 | 0.3849 |
| 1.195 | 6.7438 | 0.5005 | 0.0333 | 0.0742 | 20.9358 | 0.3848 |
| 1.25 | 6.7257 | 0.5139 | 0.0357 | 0.0764 | 22.5158 | 0.3853 |
| 1.3 | 6.7051 | 0.5163 | 0.0373 | 0.077 | 23.5594 | 0.3859 |
| 1.36 | 6.6839 | 0.5058 | 0.0383 | 0.0757 | 24.1855 | 0.3865 |
| 1.415 | 6.6788 | 0.492 | 0.0387 | 0.0737 | 24.4857 | 0.3867 |
| 1.475 | 6.6827 | 0.4861 | 0.0399 | 0.0727 | 25.2099 | 0.3866 |
| 1.54 | 6.6861 | 0.4911 | 0.0421 | 0.0734 | 26.5844 | 0.3865 |
| 1.605 | 6.6839 | 0.5026 | 0.0449 | 0.0752 | 28.3588 | 0.3865 |
| 1.675 | 6.6717 | 0.5175 | 0.0482 | 0.0776 | 30.5005 | 0.3869 |
| 1.745 | 6.644 | 0.5234 | 0.0508 | 0.0788 | 32.206 | 0.3877 |
| 1.82 | 6.6299 | 0.4915 | 0.0497 | 0.0741 | 31.5757 | 0.3881 |
| 1.9 | 6.6485 | 0.4931 | 0.0521 | 0.0742 | 33.0278 | 0.3876 |
| 1.98 | 6.6506 | 0.5027 | 0.0553 | 0.0756 | 35.08 | 0.3875 |
| 2.065 | 6.6506 | 0.5127 | 0.0589 | 0.0771 | 37.3167 | 0.3875 |
| 2.155 | 6.6477 | 0.5262 | 0.0631 | 0.0792 | 39.9739 | 0.3875 |
| 2.25 | 6.6393 | 0.5414 | 0.0677 | 0.0815 | 42.9642 | 0.3878 |
| 2.345 | 6.6255 | 0.5472 | 0.0713 | 0.0826 | 45.3016 | 0.3882 |
| 2.445 | 6.628 | 0.5499 | 0.0748 | 0.083 | 47.4593 | 0.3881 |
| 2.55 | 6.6251 | 0.5668 | 0.0804 | 0.0856 | 51.0335 | 0.3882 |
| 2.66 | 6.6205 | 0.5817 | 0.086 | 0.0879 | 54.6427 | 0.3883 |
| 2.775 | 6.6154 | 0.6006 | 0.0927 | 0.0908 | 58.8767 | 0.3884 |
| 2.89 | 6.6028 | 0.621 | 0.0998 | 0.094 | 63.4576 | 0.3887 |
| 3.015 | 6.5842 | 0.631 | 0.1058 | 0.0958 | 67.357 | 0.3893 |
| 3.145 | 6.5802 | 0.6376 | 0.1115 | 0.0969 | 71.0214 | 0.3894 |
| 3.28 | 6.5775 | 0.654 | 0.1193 | 0.0994 | 75.9906 | 0.3894 |
| 3.42 | 6.5726 | 0.6726 | 0.1279 | 0.1023 | 81.5013 | 0.3896 |
| 3.57 | 6.5661 | 0.6945 | 0.1379 | 0.1058 | 87.8929 | 0.3897 |
| 3.72 | 6.5539 | 0.7182 | 0.1486 | 0.1096 | 94.7847 | 0.39 |
| 3.88 | 6.5393 | 0.7372 | 0.159 | 0.1127 | 101.5743 | 0.3904 |
| 4.045 | 6.5256 | 0.7513 | 0.169 | 0.1151 | 108.0309 | 0.3908 |


A.P. HILL, OFF RD , File: 16JL61041
20 deg C, Mv = 17.6%, 1.510 g/cc (dry)
Real
Imaginary
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz


A.P. HILL, OFF RD , File: 16JL61041
20 deg C, Mv = 17.6%, 1.510 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
100
10
1
0.1
0.01
10
1
0.1
0.01
0.001
0.01
0.1
1
10

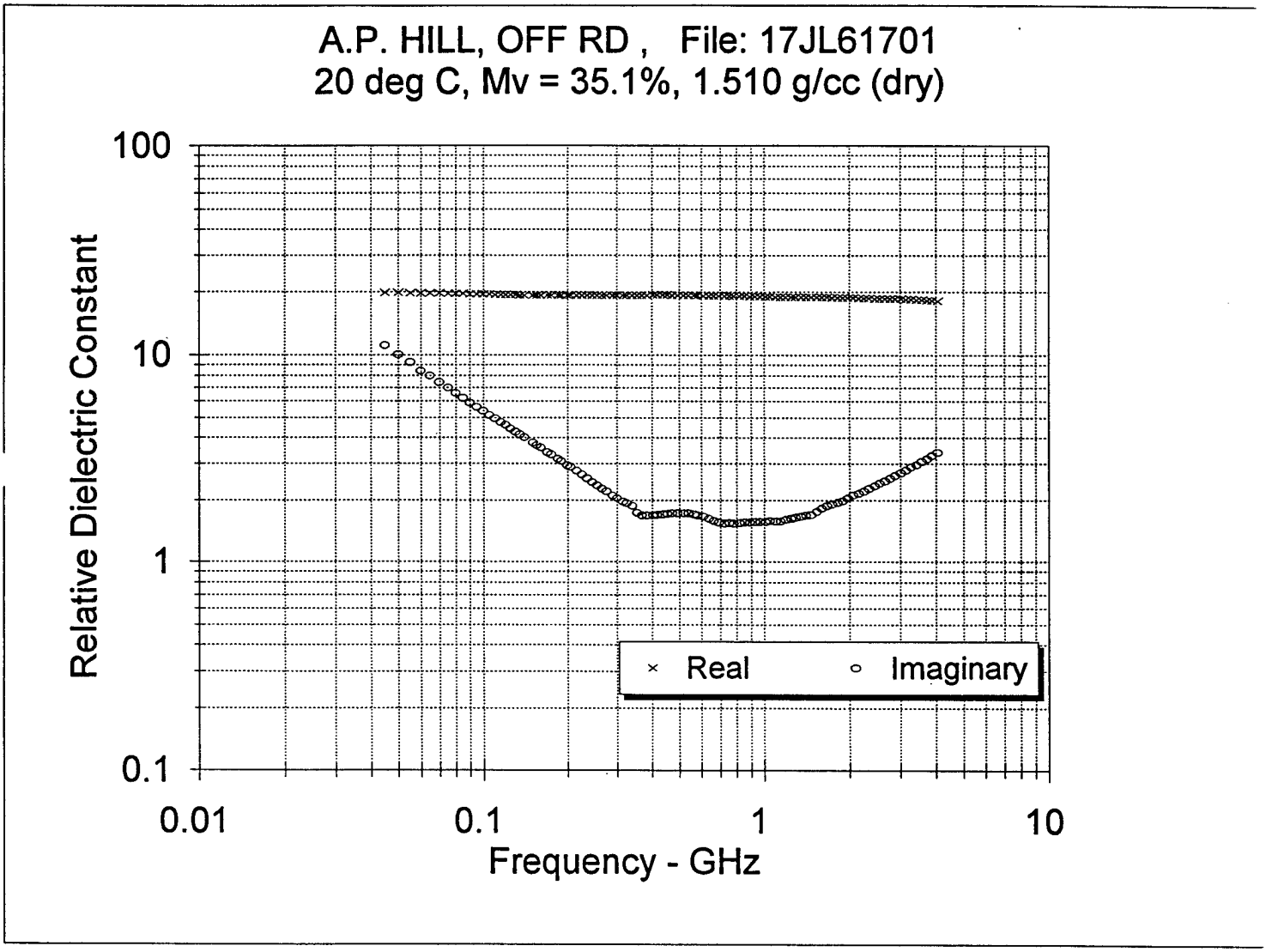

A.P. HILL, OFF RD , File: 16JL61041
20 deg C, Mv = 17.6%, 1.510 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
1000
100
10
1
0.01
0.1
1
10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

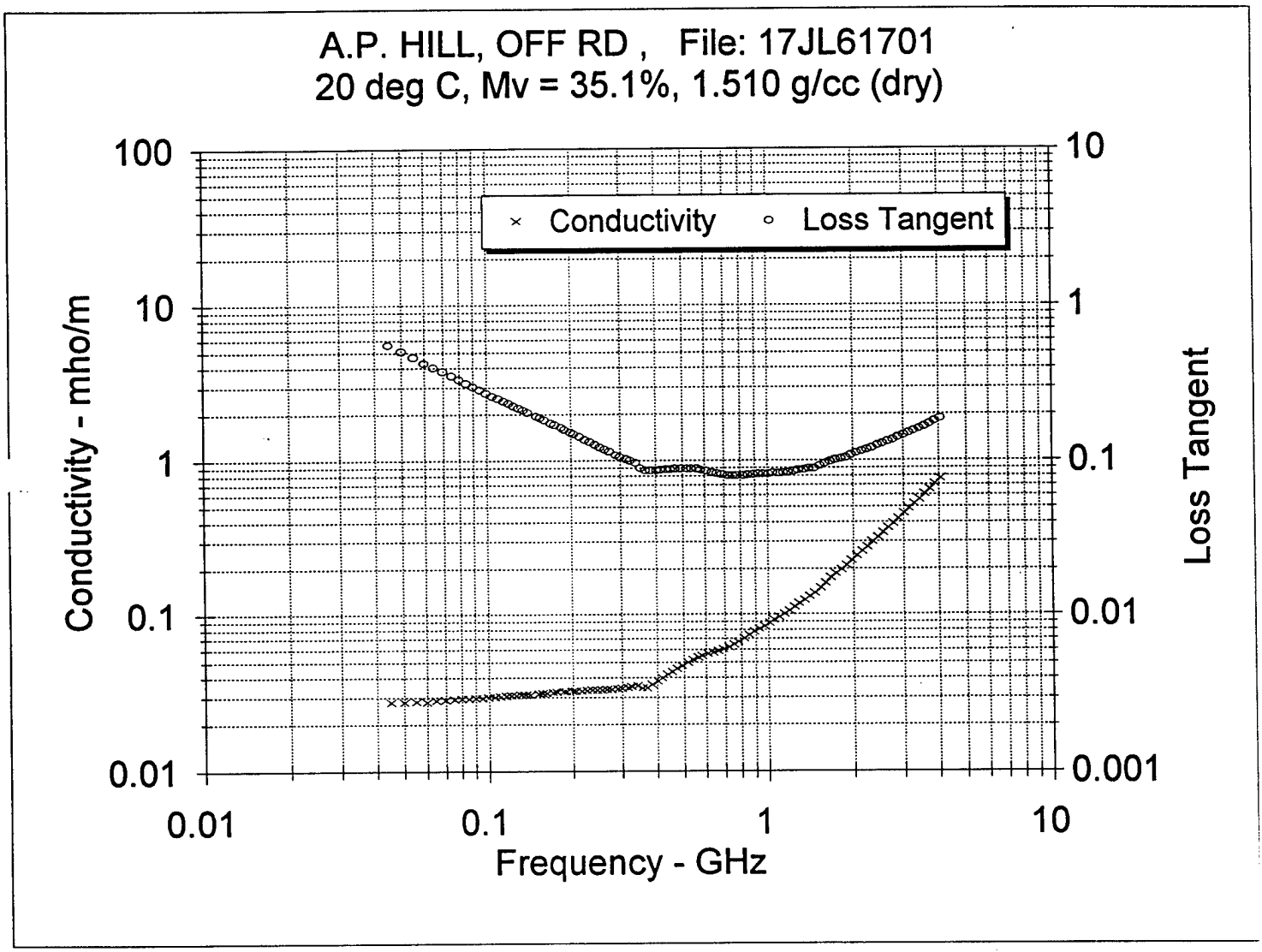
17JL61701
A.P. HILL, OFF RD
9.7
3
35.1
20
1.51

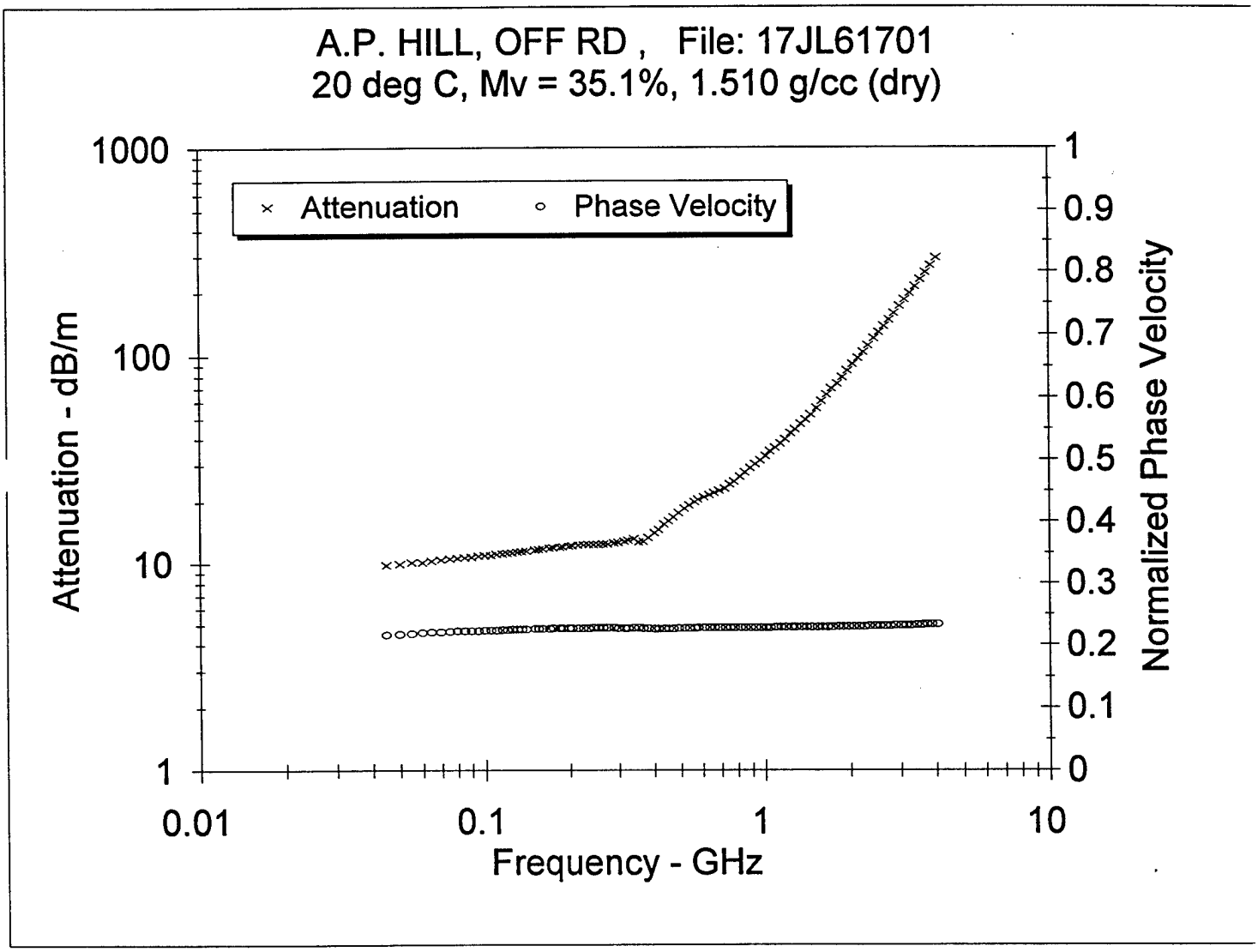
A.P. HILL, OFF RD , File: 17JL61701
20 deg C, Mv = 35.1%, 1.510 g/cc (dry)

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.045 | 19.8122 | 11.0809 | 0.0277 | 0.5593 | 9.8376 | 0.2169 |
| 0.05 | 19.7959 | 10.0503 | 0.0279 | 0.5077 | 9.9747 | 0.2182 |
| 0.055 | 19.7486 | 9.2067 | 0.0282 | 0.4662 | 10.1066 | 0.2194 |
| 0.06 | 19.7283 | 8.3893 | 0.028 | 0.4252 | 10.0917 | 0.2204 |
| 0.065 | 19.6991 | 7.9044 | 0.0286 | 0.4013 | 10.3311 | 0.2211 |
| 0.07 | 19.6825 | 7.3887 | 0.0288 | 0.3754 | 10.4278 | 0.2217 |
| 0.075 | 19.648 | 6.9391 | 0.0289 | 0.3532 | 10.5214 | 0.2223 |
| 0.08 | 19.6255 | 6.5649 | 0.0292 | 0.3345 | 10.6394 | 0.2227 |
| 0.085 | 19.5856 | 6.2008 | 0.0293 | 0.3166 | 10.7027 | 0.2232 |
| 0.09 | 19.5609 | 5.8859 | 0.0295 | 0.3009 | 10.7758 | 0.2236 |
| 0.095 | 19.5461 | 5.6094 | 0.0296 | 0.287 | 10.8546 | 0.2239 |
| 0.1 | 19.5089 | 5.3602 | 0.0298 | 0.2748 | 10.9376 | 0.2243 |
| 0.105 | 19.478 | 5.1184 | 0.0299 | 0.2628 | 10.9835 | 0.2247 |
| 0.11 | 19.4722 | 4.931 | 0.0302 | 0.2532 | 11.0933 | 0.2248 |
| 0.115 | 19.4408 | 4.7347 | 0.0303 | 0.2435 | 11.1512 | 0.2252 |
| 0.12 | 19.4298 | 4.5727 | 0.0305 | 0.2353 | 11.2466 | 0.2253 |
| 0.125 | 19.4087 | 4.4061 | 0.0306 | 0.227 | 11.2997 | 0.2256 |
| 0.13 | 19.39 | 4.2578 | 0.0308 | 0.2196 | 11.3661 | 0.2258 |
| 0.135 | 19.3725 | 4.1216 | 0.0309 | 0.2128 | 11.4348 | 0.2259 |
| 0.14 | 19.352 | 3.9953 | 0.0311 | 0.2065 | 11.5047 | 0.2261 |
| 0.15 | 19.3234 | 3.7681 | 0.0314 | 0.195 | 11.6406 | 0.2264 |
| 0.155 | 19.3105 | 3.668 | 0.0316 | 0.19 | 11.716 | 0.2266 |
| 0.16 | 19.2954 | 3.5679 | 0.0317 | 0.1849 | 11.7709 | 0.2267 |
| 0.17 | 19.2698 | 3.3883 | 0.032 | 0.1758 | 11.89 | 0.2269 |
| 0.175 | 19.2549 | 3.3017 | 0.0321 | 0.1715 | 11.9335 | 0.2271 |
| 0.185 | 19.2306 | 3.1461 | 0.0324 | 0.1636 | 12.0323 | 0.2273 |
| 0.19 | 19.2226 | 3.0768 | 0.0325 | 0.1601 | 12.0896 | 0.2274 |
| 0.2 | 19.2068 | 2.938 | 0.0327 | 0.153 | 12.1601 | 0.2275 |
| 0.205 | 19.2034 | 2.8716 | 0.0327 | 0.1495 | 12.1849 | 0.2276 |
| 0.215 | 19.1889 | 2.7542 | 0.0329 | 0.1435 | 12.2642 | 0.2277 |
| 0.225 | 19.183 | 2.6374 | 0.033 | 0.1375 | 12.2948 | 0.2278 |
| 0.235 | 19.1795 | 2.5394 | 0.0332 | 0.1324 | 12.3675 | 0.2278 |
| 0.245 | 19.1776 | 2.437 | 0.0332 | 0.1271 | 12.3765 | 0.2279 |
| 0.255 | 19.1836 | 2.3459 | 0.0333 | 0.1223 | 12.4 | 0.2279 |
| 0.265 | 19.1829 | 2.2647 | 0.0334 | 0.1181 | 12.4418 | 0.2279 |
| 0.275 | 19.1901 | 2.1892 | 0.0335 | 0.1141 | 12.4799 | 0.2279 |
| 0.29 | 19.2047 | 2.0916 | 0.0337 | 0.1089 | 12.5713 | 0.2279 |
| 0.3 | 19.2155 | 2.0351 | 0.034 | 0.1059 | 12.6511 | 0.2278 |
| 0.315 | 19.2288 | 1.9679 | 0.0345 | 0.1023 | 12.8412 | 0.2277 |
| 0.325 | 19.2285 | 1.9285 | 0.0349 | 0.1003 | 12.9848 | 0.2278 |
| 0.34 | 19.2056 | 1.867 | 0.0353 | 0.0972 | 13.1598 | 0.2279 |
| 0.355 | 19.2046 | 1.7253 | 0.0341 | 0.0898 | 12.6996 | 0.228 |
| 0.37 | 19.3158 | 1.678 | 0.0345 | 0.0869 | 12.8375 | 0.2273 |
| 0.385 | 19.3602 | 1.6805 | 0.036 | 0.0868 | 13.3619 | 0.2271 |
| 0.405 | 19.3858 | 1.6857 | 0.038 | 0.087 | 14.0908 | 0.2269 |
| 0.42 | 19.3932 | 1.6909 | 0.0395 | 0.0872 | 14.655 | 0.2269 |
| 0.44 | 19.3883 | 1.7011 | 0.0416 | 0.0877 | 15.4465 | 0.2269 |
| 0.455 | 19.3801 | 1.7073 | 0.0432 | 0.0881 | 16.0346 | 0.2269 |
| 0.475 | 19.3621 | 1.715 | 0.0453 | 0.0886 | 16.8228 | 0.227 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.495 | 19.3373 | 1.7208 | 0.0474 | 0.089 | 17.6017 | 0.2272 |
| 0.52 | 19.304 | 1.7194 | 0.0497 | 0.0891 | 18.4917 | 0.2274 |
| 0.54 | 19.2745 | 1.7146 | 0.0515 | 0.089 | 19.1632 | 0.2276 |
| 0.565 | 19.2321 | 1.7002 | 0.0534 | 0.0884 | 19.9049 | 0.2278 |
| 0.585 | 19.2004 | 1.682 | 0.0547 | 0.0876 | 20.4054 | 0.228 |
| 0.61 | 19.1626 | 1.6544 | 0.0561 | 0.0863 | 20.9503 | 0.2282 |
| 0.64 | 19.1305 | 1.6141 | 0.0574 | 0.0844 | 21.4638 | 0.2284 |
| 0.665 | 19.1127 | 1.5846 | 0.0586 | 0.0829 | 21.9059 | 0.2285 |
| 0.695 | 19.1048 | 1.5533 | 0.06 | 0.0813 | 22.4473 | 0.2286 |
| 0.725 | 19.1103 | 1.5358 | 0.0619 | 0.0804 | 23.1495 | 0.2286 |
| 0.755 | 19.1181 | 1.5397 | 0.0646 | 0.0805 | 24.1632 | 0.2285 |
| 0.785 | 19.1134 | 1.533 | 0.0669 | 0.0802 | 25.0165 | 0.2286 |
| 0.82 | 19.1033 | 1.5387 | 0.0702 | 0.0805 | 26.2369 | 0.2286 |
| 0.855 | 19.0867 | 1.5478 | 0.0736 | 0.0811 | 27.5296 | 0.2287 |
| 0.895 | 19.0617 | 1.5577 | 0.0775 | 0.0817 | 29.0215 | 0.2289 |
| 0.93 | 19.0393 | 1.5622 | 0.0808 | 0.0821 | 30.2605 | 0.229 |
| 0.97 | 19.017 | 1.5619 | 0.0842 | 0.0821 | 31.5735 | 0.2291 |
| 1.015 | 19.0044 | 1.5649 | 0.0883 | 0.0823 | 33.1128 | 0.2292 |
| 1.055 | 18.9876 | 1.5812 | 0.0928 | 0.0833 | 34.7913 | 0.2293 |
| 1.1 | 18.9621 | 1.5717 | 0.0961 | 0.0829 | 36.0808 | 0.2294 |
| 1.15 | 18.9655 | 1.5751 | 0.1007 | 0.083 | 37.7996 | 0.2294 |
| 1.195 | 18.963 | 1.5937 | 0.1059 | 0.084 | 39.7443 | 0.2294 |
| 1.25 | 18.9517 | 1.6215 | 0.1127 | 0.0856 | 42.3097 | 0.2295 |
| 1.3 | 18.9359 | 1.6397 | 0.1185 | 0.0866 | 44.5156 | 0.2296 |
| 1.36 | 18.9197 | 1.6554 | 0.1252 | 0.0875 | 47.0344 | 0.2297 |
| 1.415 | 18.9114 | 1.6712 | 0.1315 | 0.0884 | 49.4143 | 0.2297 |
| 1.475 | 18.9282 | 1.6919 | 0.1388 | 0.0894 | 52.1223 | 0.2296 |
| 1.54 | 18.941 | 1.7468 | 0.1496 | 0.0922 | 56.1636 | 0.2295 |
| 1.605 | 18.9259 | 1.8122 | 0.1617 | 0.0958 | 60.7433 | 0.2296 |
| 1.675 | 18.8905 | 1.8683 | 0.174 | 0.0989 | 65.4125 | 0.2298 |
| 1.745 | 18.8583 | 1.9021 | 0.1846 | 0.1009 | 69.4321 | 0.23 |
| 1.82 | 18.8398 | 1.931 | 0.1954 | 0.1025 | 73.5532 | 0.2301 |
| 1.9 | 18.8362 | 1.976 | 0.2088 | 0.1049 | 78.5759 | 0.2301 |
| 1.98 | 18.8206 | 2.0402 | 0.2246 | 0.1084 | 84.5723 | 0.2302 |
| 2.065 | 18.7822 | 2.1007 | 0.2412 | 0.1118 | 90.9031 | 0.2304 |
| 2.155 | 18.7458 | 2.1508 | 0.2577 | 0.1147 | 97.215 | 0.2306 |
| 2.25 | 18.7185 | 2.2007 | 0.2753 | 0.1176 | 103.9222 | 0.2307 |
| 2.345 | 18.696 | 2.2675 | 0.2957 | 0.1213 | 111.6495 | 0.2309 |
| 2.445 | 18.6591 | 2.3383 | 0.3179 | 0.1253 | 120.151 | 0.2311 |
| 2.55 | 18.6198 | 2.4017 | 0.3406 | 0.129 | 128.8318 | 0.2313 |
| 2.66 | 18.594 | 2.4631 | 0.3643 | 0.1325 | 137.9048 | 0.2314 |
| 2.775 | 18.5757 | 2.5345 | 0.3911 | 0.1364 | 148.0896 | 0.2315 |
| 2.89 | 18.5571 | 2.612 | 0.4198 | 0.1408 | 159.0004 | 0.2316 |
| 3.015 | 18.5283 | 2.6972 | 0.4522 | 0.1456 | 171.3867 | 0.2317 |
| 3.145 | 18.4857 | 2.7835 | 0.4868 | 0.1506 | 184.6812 | 0.2319 |
| 3.28 | 18.4321 | 2.8665 | 0.5228 | 0.1555 | 198.5977 | 0.2322 |
| 3.42 | 18.3763 | 2.9518 | 0.5614 | 0.1606 | 213.5193 | 0.2325 |
| 3.57 | 18.3166 | 3.0499 | 0.6055 | 0.1665 | 230.6167 | 0.2329 |
| 3.72 | 18.2654 | 3.1537 | 0.6524 | 0.1727 | 248.7702 | 0.2331 |
| 3.88 | 18.2199 | 3.2747 | 0.7065 | 0.1797 | 269.676 | 0.2333 |
| 4.045 | 18.1824 | 3.3992 | 0.7646 | 0.1869 | 292.0353 | 0.2335 |


A.P. HILL, OFF RD , File: 17JL61701
20 deg C, Mv = 35.1%, 1.510 g/cc (dry)
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz
Real
Imaginary


A.P. HILL, OFF RD , File: 17JL61701
20 deg C, Mv = 35.1%, 1.510 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
100
10
1
0.1
0.01
10
1
0.1
0.01
0.001
0.01
0.1
1
10

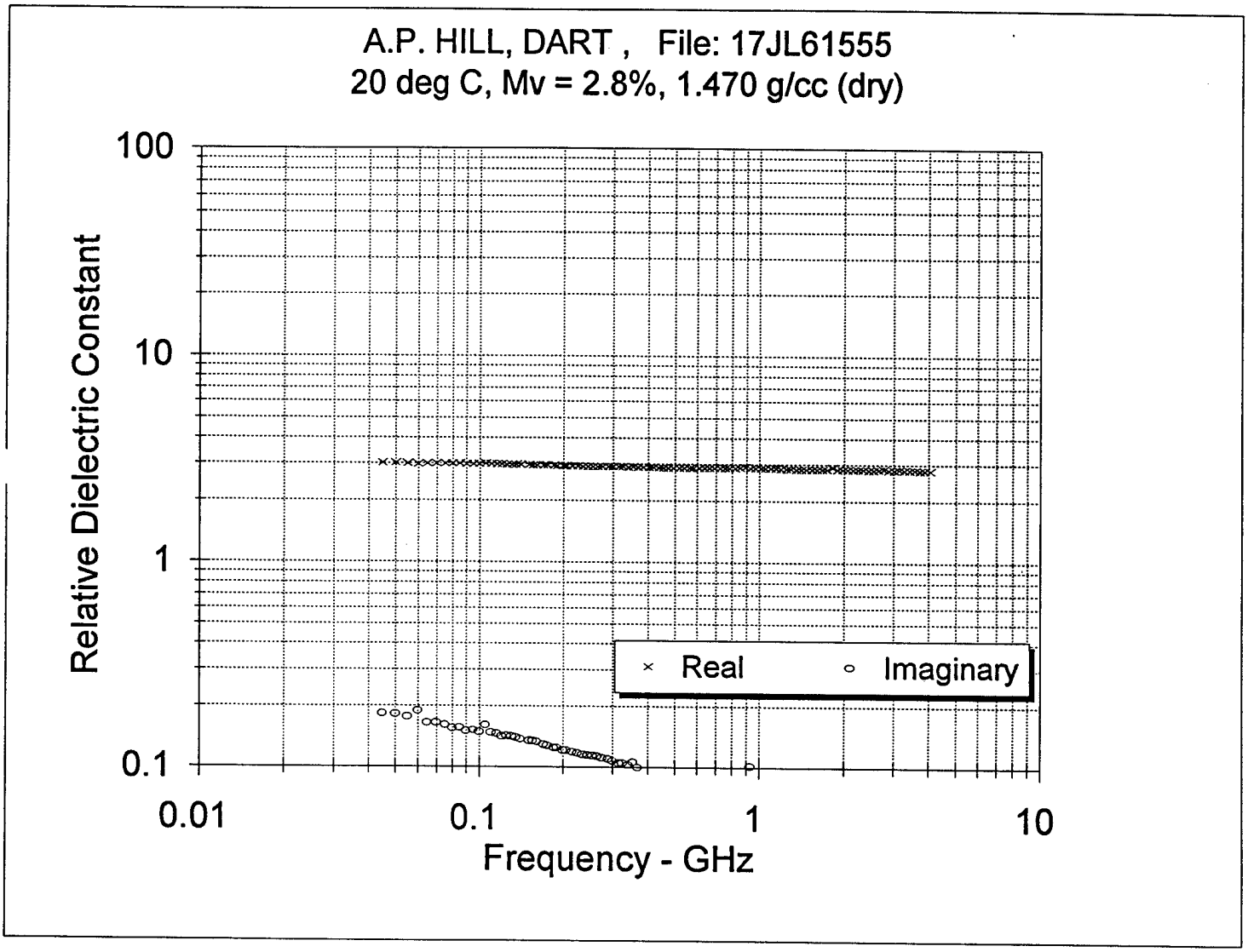

A.P. HILL, OFF RD , File: 17JL61701
20 deg C, Mv = 35.1%, 1.510 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
1000
100
10
1
0.01
0.1
1
10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

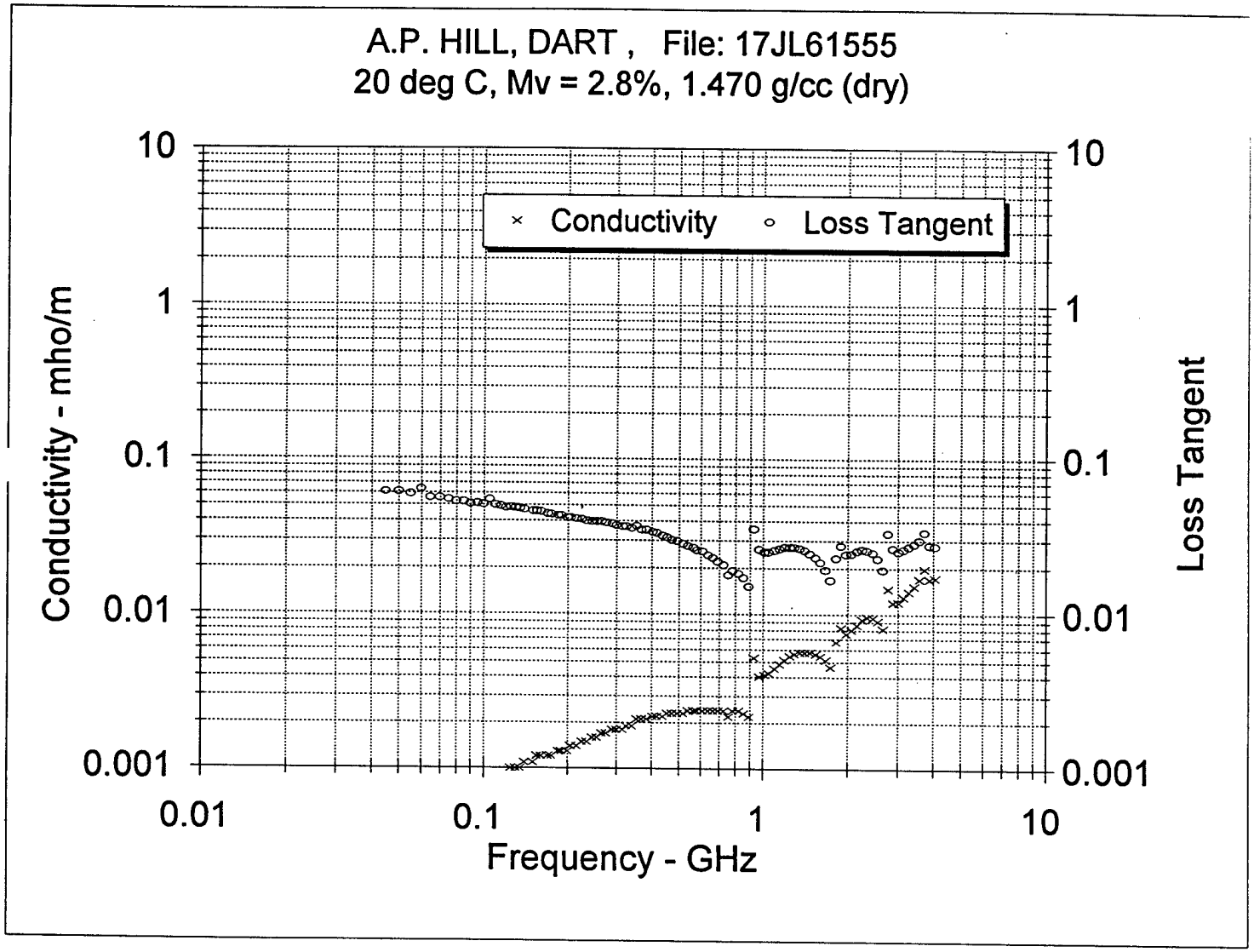
17JL61555
A.P. HILL, DART
9.7
4
2.8
20
1.47

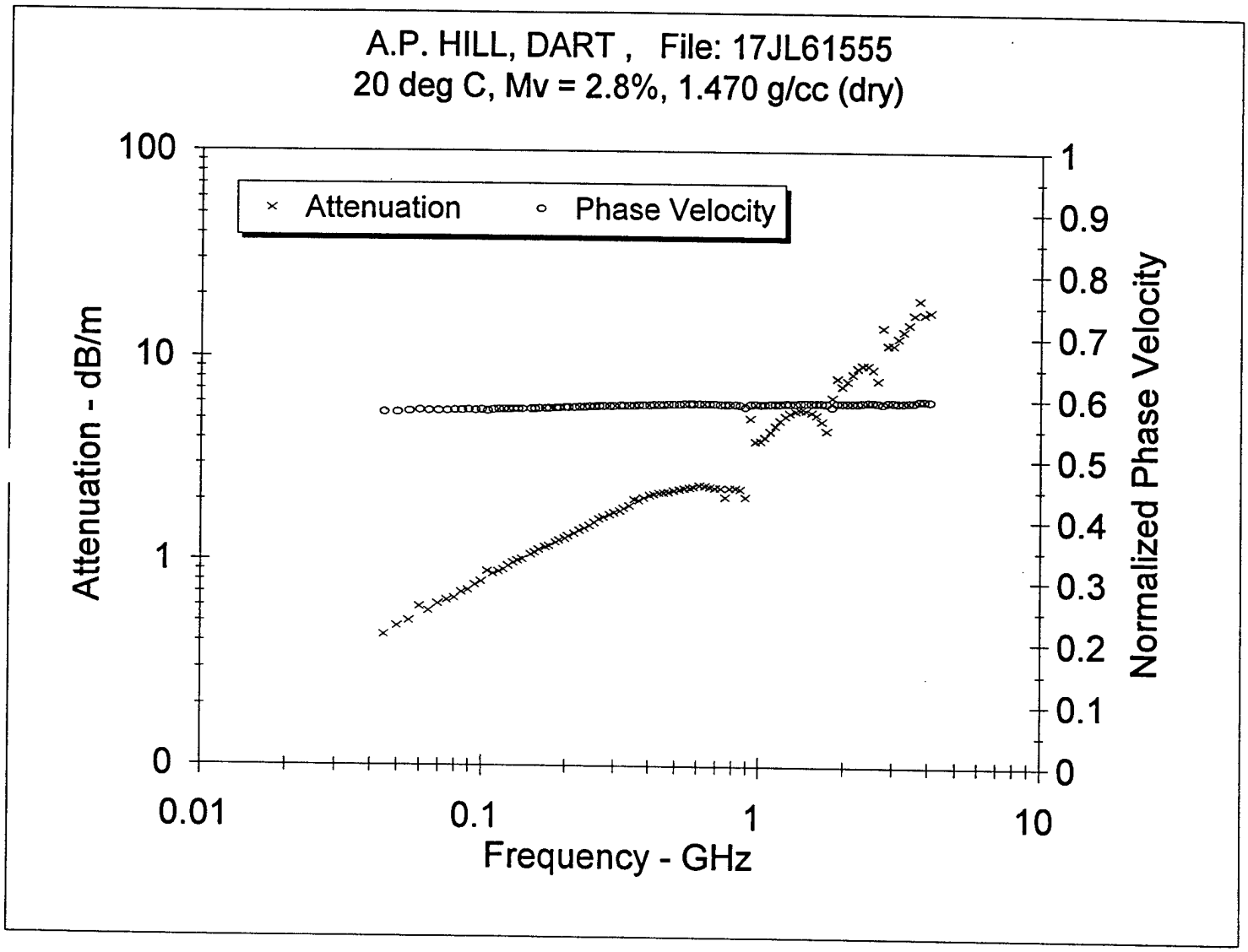
A.P. HILL, DART , File: 17JL61555
20 deg C, Mv = 2.8%, 1.470 g/cc (dry)

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.045 | 3.0009 | 0.1823 | 0.0005 | 0.0607 | 0.4305 | 0.577 |
| 0.05 | 2.9997 | 0.1814 | 0.0005 | 0.0605 | 0.476 | 0.5771 |
| 0.055 | 2.9861 | 0.1754 | 0.0005 | 0.0587 | 0.5076 | 0.5784 |
| 0.06 | 2.9698 | 0.188 | 0.0006 | 0.0633 | 0.5951 | 0.58 |
| 0.065 | 2.9805 | 0.1651 | 0.0006 | 0.0554 | 0.565 | 0.579 |
| 0.07 | 2.9795 | 0.1653 | 0.0006 | 0.0555 | 0.6095 | 0.5791 |
| 0.075 | 2.9784 | 0.1609 | 0.0007 | 0.054 | 0.6359 | 0.5792 |
| 0.08 | 2.9724 | 0.1552 | 0.0007 | 0.0522 | 0.655 | 0.5798 |
| 0.085 | 2.9718 | 0.1561 | 0.0007 | 0.0525 | 0.7 | 0.5799 |
| 0.09 | 2.9607 | 0.1506 | 0.0008 | 0.0509 | 0.7165 | 0.581 |
| 0.095 | 2.9694 | 0.1517 | 0.0008 | 0.0511 | 0.7606 | 0.5801 |
| 0.1 | 2.9602 | 0.1488 | 0.0008 | 0.0503 | 0.7866 | 0.581 |
| 0.105 | 2.9792 | 0.1608 | 0.0009 | 0.054 | 0.8896 | 0.5791 |
| 0.11 | 2.9585 | 0.148 | 0.0009 | 0.05 | 0.8606 | 0.5812 |
| 0.115 | 2.9561 | 0.1454 | 0.0009 | 0.0492 | 0.8844 | 0.5814 |
| 0.12 | 2.9567 | 0.142 | 0.0009 | 0.048 | 0.9011 | 0.5814 |
| 0.125 | 2.9525 | 0.143 | 0.001 | 0.0484 | 0.946 | 0.5818 |
| 0.13 | 2.9491 | 0.1421 | 0.001 | 0.0482 | 0.9783 | 0.5821 |
| 0.135 | 2.9471 | 0.1397 | 0.001 | 0.0474 | 0.9991 | 0.5823 |
| 0.14 | 2.9452 | 0.1375 | 0.0011 | 0.0467 | 1.0201 | 0.5825 |
| 0.15 | 2.9407 | 0.1353 | 0.0011 | 0.046 | 1.0759 | 0.583 |
| 0.155 | 2.9382 | 0.1346 | 0.0012 | 0.0458 | 1.1065 | 0.5832 |
| 0.16 | 2.9352 | 0.1332 | 0.0012 | 0.0454 | 1.1314 | 0.5835 |
| 0.17 | 2.9317 | 0.1294 | 0.0012 | 0.0441 | 1.1686 | 0.5839 |
| 0.175 | 2.9292 | 0.1281 | 0.0012 | 0.0437 | 1.1909 | 0.5841 |
| 0.185 | 2.9255 | 0.125 | 0.0013 | 0.0427 | 1.229 | 0.5845 |
| 0.19 | 2.924 | 0.1249 | 0.0013 | 0.0427 | 1.2616 | 0.5847 |
| 0.2 | 2.9195 | 0.1212 | 0.0013 | 0.0415 | 1.2902 | 0.5851 |
| 0.205 | 2.918 | 0.1212 | 0.0014 | 0.0415 | 1.3226 | 0.5853 |
| 0.215 | 2.914 | 0.1192 | 0.0014 | 0.0409 | 1.3651 | 0.5857 |
| 0.225 | 2.9127 | 0.1179 | 0.0015 | 0.0405 | 1.4139 | 0.5858 |
| 0.235 | 2.907 | 0.1158 | 0.0015 | 0.0398 | 1.4516 | 0.5864 |
| 0.245 | 2.9055 | 0.1147 | 0.0016 | 0.0395 | 1.4993 | 0.5865 |
| 0.255 | 2.9006 | 0.1141 | 0.0016 | 0.0393 | 1.5531 | 0.587 |
| 0.265 | 2.8975 | 0.1138 | 0.0017 | 0.0393 | 1.6106 | 0.5874 |
| 0.275 | 2.8934 | 0.1118 | 0.0017 | 0.0386 | 1.6437 | 0.5878 |
| 0.29 | 2.8892 | 0.1098 | 0.0018 | 0.038 | 1.7042 | 0.5882 |
| 0.3 | 2.8874 | 0.1081 | 0.0018 | 0.0374 | 1.7349 | 0.5884 |
| 0.315 | 2.8806 | 0.1048 | 0.0018 | 0.0364 | 1.7693 | 0.5891 |
| 0.325 | 2.8816 | 0.105 | 0.0019 | 0.0364 | 1.8278 | 0.589 |
| 0.34 | 2.8782 | 0.1031 | 0.0019 | 0.0358 | 1.8782 | 0.5893 |
| 0.355 | 2.8816 | 0.1061 | 0.0021 | 0.0368 | 2.0175 | 0.589 |
| 0.37 | 2.8753 | 0.1004 | 0.0021 | 0.0349 | 1.9924 | 0.5897 |
| 0.385 | 2.8734 | 0.0999 | 0.0021 | 0.0348 | 2.0631 | 0.5898 |
| 0.405 | 2.8701 | 0.0974 | 0.0022 | 0.0339 | 2.1181 | 0.5902 |
| 0.42 | 2.8681 | 0.0951 | 0.0022 | 0.0332 | 2.1451 | 0.5904 |
| 0.44 | 2.8647 | 0.0916 | 0.0022 | 0.032 | 2.1669 | 0.5908 |
| 0.455 | 2.8632 | 0.0894 | 0.0023 | 0.0312 | 2.1867 | 0.5909 |
| 0.475 | 2.8614 | 0.0861 | 0.0023 | 0.0301 | 2.1989 | 0.5911 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.495 | 2.8591 | 0.0842 | 0.0023 | 0.0295 | 2.2419 | 0.5913 |
| 0.52 | 2.8567 | 0.0809 | 0.0023 | 0.0283 | 2.2648 | 0.5916 |
| 0.54 | 2.8548 | 0.0785 | 0.0024 | 0.0275 | 2.2821 | 0.5918 |
| 0.565 | 2.8532 | 0.076 | 0.0024 | 0.0267 | 2.3135 | 0.592 |
| 0.585 | 2.8525 | 0.074 | 0.0024 | 0.0259 | 2.33 | 0.592 |
| 0.61 | 2.8518 | 0.0721 | 0.0024 | 0.0253 | 2.3694 | 0.5921 |
| 0.64 | 2.8521 | 0.0683 | 0.0024 | 0.0239 | 2.3538 | 0.5921 |
| 0.665 | 2.8539 | 0.0653 | 0.0024 | 0.0229 | 2.3383 | 0.5919 |
| 0.695 | 2.8548 | 0.0619 | 0.0024 | 0.0217 | 2.3142 | 0.5918 |
| 0.725 | 2.8561 | 0.0591 | 0.0024 | 0.0207 | 2.3075 | 0.5917 |
| 0.755 | 2.8622 | 0.0513 | 0.0022 | 0.0179 | 2.083 | 0.5911 |
| 0.785 | 2.8585 | 0.0547 | 0.0024 | 0.0191 | 2.308 | 0.5914 |
| 0.82 | 2.861 | 0.0524 | 0.0024 | 0.0183 | 2.3093 | 0.5912 |
| 0.855 | 2.8669 | 0.0494 | 0.0023 | 0.0172 | 2.2693 | 0.5906 |
| 0.895 | 2.9027 | 0.0435 | 0.0022 | 0.015 | 2.0783 | 0.5869 |
| 0.93 | 2.857 | 0.1018 | 0.0053 | 0.0356 | 5.0916 | 0.5915 |
| 0.97 | 2.8527 | 0.0747 | 0.004 | 0.0262 | 3.9038 | 0.592 |
| 1.015 | 2.8558 | 0.0718 | 0.0041 | 0.0251 | 3.9205 | 0.5917 |
| 1.055 | 2.8561 | 0.0719 | 0.0042 | 0.0252 | 4.08 | 0.5917 |
| 1.1 | 2.8551 | 0.0739 | 0.0045 | 0.0259 | 4.3748 | 0.5918 |
| 1.15 | 2.8522 | 0.0754 | 0.0048 | 0.0264 | 4.6709 | 0.5921 |
| 1.195 | 2.8488 | 0.0768 | 0.0051 | 0.027 | 4.9469 | 0.5924 |
| 1.25 | 2.844 | 0.0773 | 0.0054 | 0.0272 | 5.2112 | 0.5929 |
| 1.3 | 2.8395 | 0.077 | 0.0056 | 0.0271 | 5.4027 | 0.5934 |
| 1.36 | 2.8355 | 0.0753 | 0.0057 | 0.0265 | 5.5278 | 0.5938 |
| 1.415 | 2.8324 | 0.073 | 0.0057 | 0.0258 | 5.5801 | 0.5941 |
| 1.475 | 2.8287 | 0.0696 | 0.0057 | 0.0246 | 5.5519 | 0.5945 |
| 1.54 | 2.8267 | 0.0657 | 0.0056 | 0.0233 | 5.4753 | 0.5947 |
| 1.605 | 2.8268 | 0.0609 | 0.0054 | 0.0216 | 5.2898 | 0.5947 |
| 1.675 | 2.8288 | 0.0545 | 0.0051 | 0.0193 | 4.9351 | 0.5945 |
| 1.745 | 2.8351 | 0.047 | 0.0046 | 0.0166 | 4.4287 | 0.5939 |
| 1.82 | 2.8951 | 0.0664 | 0.0067 | 0.0229 | 6.4625 | 0.5877 |
| 1.9 | 2.8285 | 0.0781 | 0.0083 | 0.0276 | 8.0245 | 0.5945 |
| 1.98 | 2.8308 | 0.0686 | 0.0076 | 0.0242 | 7.344 | 0.5943 |
| 2.065 | 2.833 | 0.0697 | 0.008 | 0.0246 | 7.7725 | 0.5941 |
| 2.155 | 2.8311 | 0.0721 | 0.0086 | 0.0255 | 8.402 | 0.5943 |
| 2.25 | 2.8277 | 0.0741 | 0.0093 | 0.0262 | 9.0146 | 0.5946 |
| 2.345 | 2.8231 | 0.0733 | 0.0096 | 0.0259 | 9.2982 | 0.5951 |
| 2.445 | 2.8193 | 0.0701 | 0.0095 | 0.0249 | 9.2865 | 0.5955 |
| 2.55 | 2.8181 | 0.0642 | 0.0091 | 0.0228 | 8.8758 | 0.5957 |
| 2.66 | 2.8237 | 0.0545 | 0.0081 | 0.0193 | 7.84 | 0.5951 |
| 2.775 | 2.8403 | 0.0948 | 0.0146 | 0.0334 | 14.2034 | 0.5933 |
| 2.89 | 2.8162 | 0.0746 | 0.012 | 0.0265 | 11.6842 | 0.5958 |
| 3.015 | 2.8198 | 0.0713 | 0.012 | 0.0253 | 11.6472 | 0.5955 |
| 3.145 | 2.821 | 0.0737 | 0.0129 | 0.0261 | 12.5576 | 0.5953 |
| 3.28 | 2.82 | 0.0769 | 0.014 | 0.0273 | 13.6669 | 0.5954 |
| 3.42 | 2.8183 | 0.0796 | 0.0151 | 0.0282 | 14.7508 | 0.5956 |
| 3.57 | 2.8186 | 0.0846 | 0.0168 | 0.03 | 16.3691 | 0.5956 |
| 3.72 | 2.7938 | 0.0948 | 0.0196 | 0.0339 | 19.1822 | 0.5982 |
| 3.88 | 2.7978 | 0.078 | 0.0168 | 0.0279 | 16.4575 | 0.5978 |
| 4.045 | 2.7985 | 0.0767 | 0.0172 | 0.0274 | 16.858 | 0.5977 |


A.P. HILL, DART , File: 17JL61555
20 deg C, Mv = 2.8%, 1.470 g/cc (dry)
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz
Real
Imaginary


A.P. HILL, DART , File: 17JL61555
20 deg C, Mv = 2.8%, 1.470 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
10
1
0.1
0.01
0.001
0.01
0.1
1
10

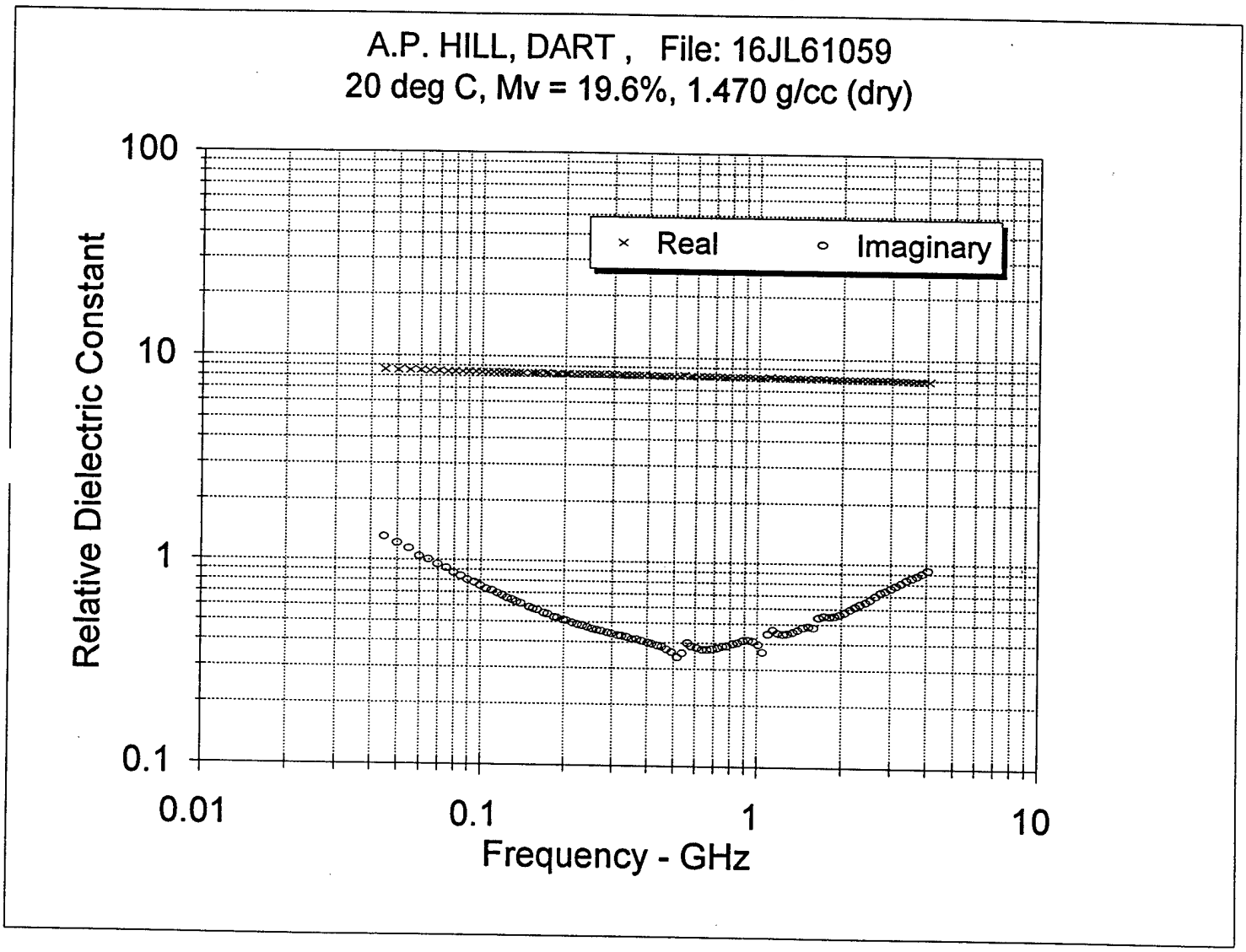

A.P. HILL, DART , File: 17JL61555
20 deg C, Mv = 2.8%, 1.470 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
100
10
1
0
0.01
0.1
1
10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

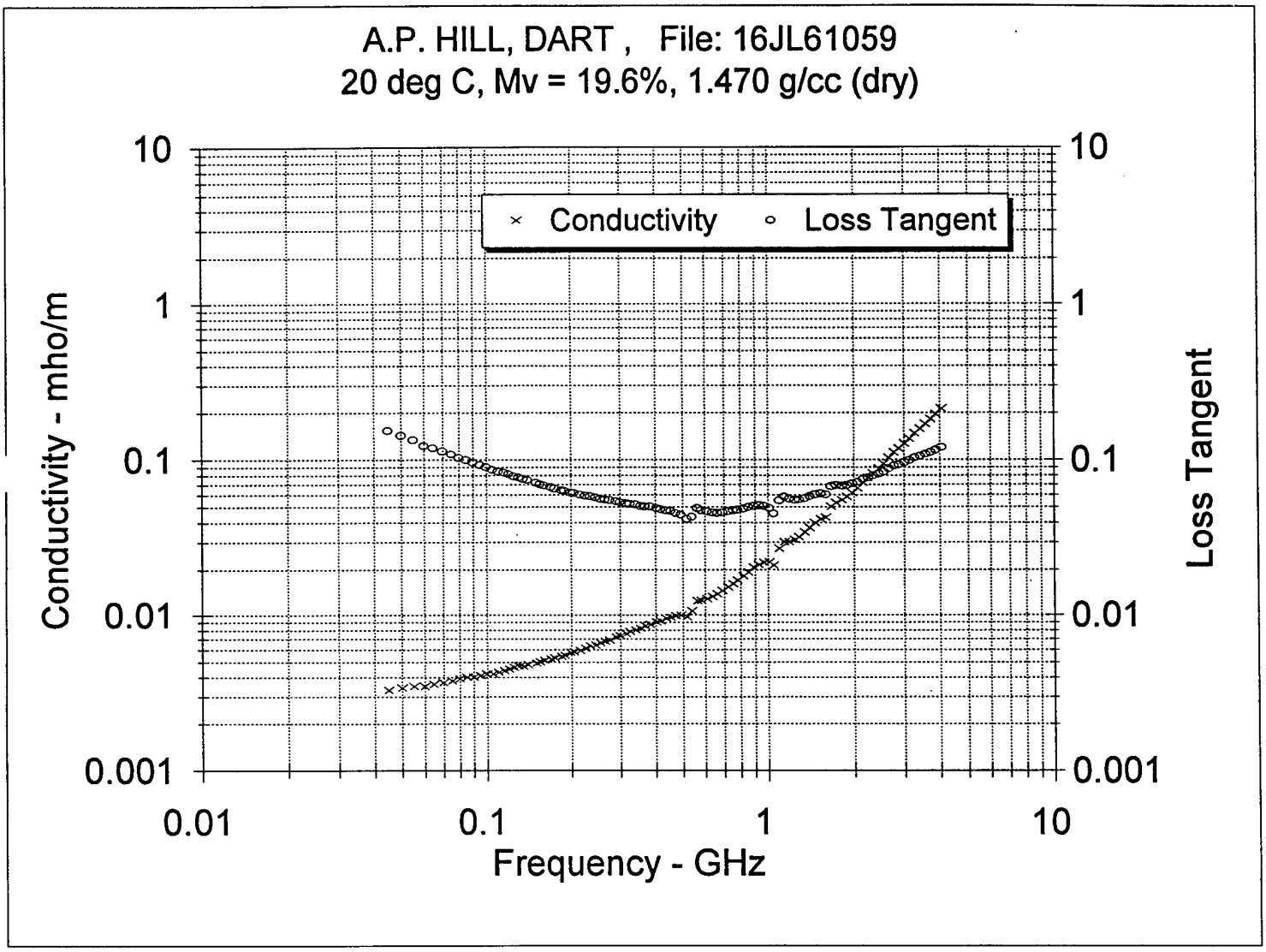
16JL61059
A.P. HILL, DART
9.7
4
19.6
20
1.47

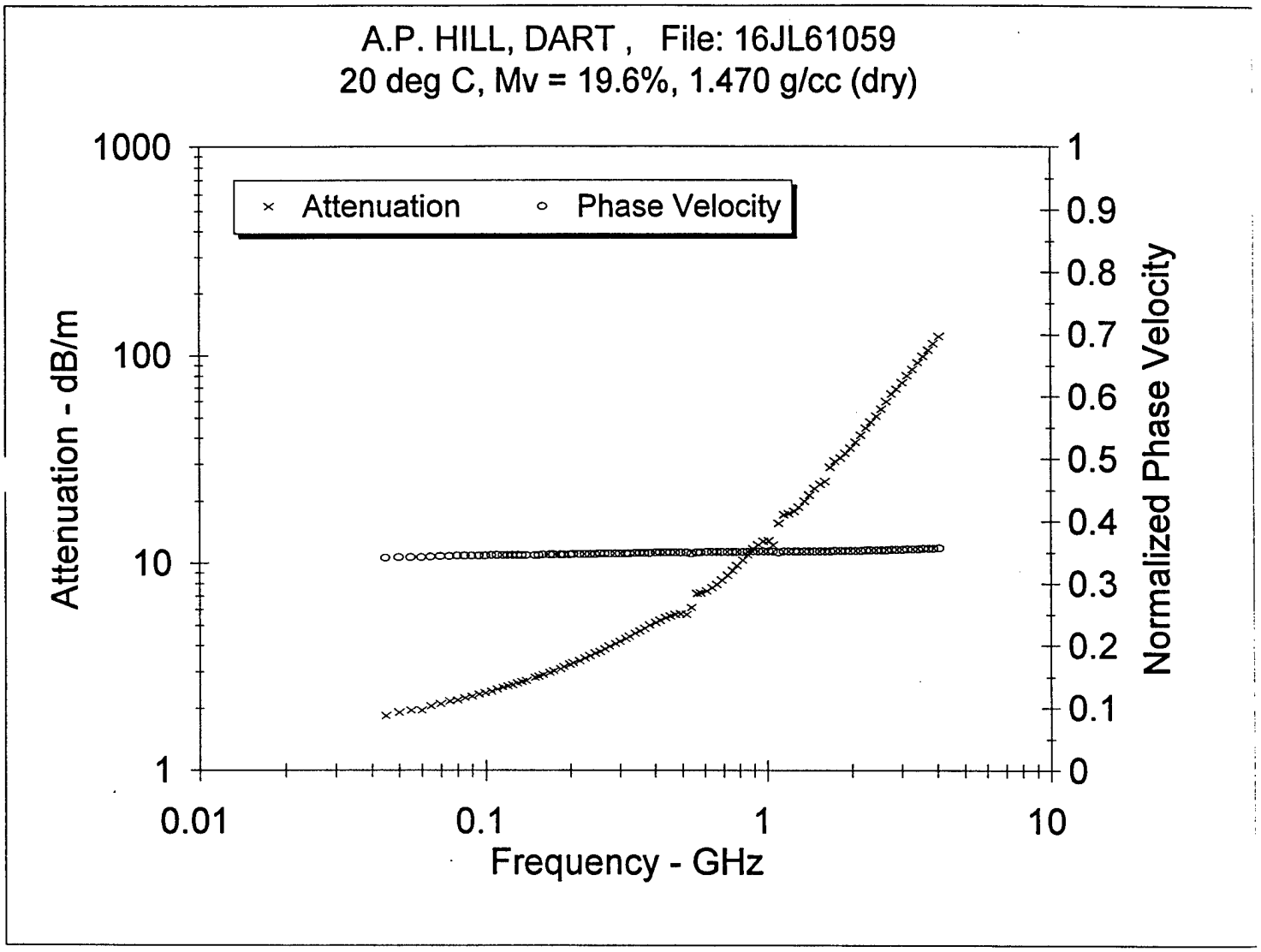
A.P. HILL, DART , File: 16JL61059
20 deg C, Mv = 19.6%, 1.470 g/cc (dry)

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.045 | 8.4837 | 1.3059 | 0.0033 | 0.1539 | 1.8298 | 0.3423 |
| 0.05 | 8.4618 | 1.2149 | 0.0034 | 0.1436 | 1.8946 | 0.3429 |
| 0.055 | 8.4399 | 1.1369 | 0.0035 | 0.1347 | 1.9534 | 0.3434 |
| 0.06 | 8.472 | 1.0426 | 0.0035 | 0.1231 | 1.9513 | 0.3429 |
| 0.065 | 8.4115 | 1.006 | 0.0036 | 0.1196 | 2.0472 | 0.3442 |
| 0.07 | 8.4019 | 0.9543 | 0.0037 | 0.1136 | 2.0928 | 0.3444 |
| 0.075 | 8.39 | 0.914 | 0.0038 | 0.1089 | 2.1496 | 0.3447 |
| 0.08 | 8.3706 | 0.8708 | 0.0039 | 0.104 | 2.1871 | 0.3452 |
| 0.085 | 8.3704 | 0.8392 | 0.004 | 0.1003 | 2.2399 | 0.3452 |
| 0.09 | 8.3566 | 0.8064 | 0.004 | 0.0965 | 2.281 | 0.3455 |
| 0.095 | 8.3557 | 0.7798 | 0.0041 | 0.0933 | 2.3286 | 0.3456 |
| 0.1 | 8.347 | 0.7527 | 0.0042 | 0.0902 | 2.3673 | 0.3458 |
| 0.105 | 8.3227 | 0.7237 | 0.0042 | 0.087 | 2.3937 | 0.3463 |
| 0.11 | 8.3304 | 0.7101 | 0.0043 | 0.0852 | 2.4593 | 0.3462 |
| 0.115 | 8.3223 | 0.6925 | 0.0044 | 0.0832 | 2.5086 | 0.3463 |
| 0.12 | 8.3152 | 0.6761 | 0.0045 | 0.0813 | 2.5571 | 0.3465 |
| 0.125 | 8.3093 | 0.6552 | 0.0046 | 0.0789 | 2.5823 | 0.3466 |
| 0.13 | 8.3027 | 0.6438 | 0.0047 | 0.0775 | 2.6399 | 0.3468 |
| 0.135 | 8.2994 | 0.6274 | 0.0047 | 0.0756 | 2.6723 | 0.3469 |
| 0.14 | 8.2945 | 0.6162 | 0.0048 | 0.0743 | 2.7229 | 0.347 |
| 0.15 | 8.2836 | 0.5905 | 0.0049 | 0.0713 | 2.7976 | 0.3472 |
| 0.155 | 8.2808 | 0.5813 | 0.005 | 0.0702 | 2.8464 | 0.3473 |
| 0.16 | 8.2753 | 0.573 | 0.0051 | 0.0692 | 2.8971 | 0.3474 |
| 0.17 | 8.2675 | 0.5535 | 0.0052 | 0.067 | 2.9751 | 0.3476 |
| 0.175 | 8.2618 | 0.5456 | 0.0053 | 0.066 | 3.0196 | 0.3477 |
| 0.185 | 8.252 | 0.5293 | 0.0054 | 0.0641 | 3.0988 | 0.3479 |
| 0.19 | 8.2527 | 0.5249 | 0.0055 | 0.0636 | 3.1559 | 0.3479 |
| 0.2 | 8.2451 | 0.5131 | 0.0057 | 0.0622 | 3.249 | 0.3481 |
| 0.205 | 8.2411 | 0.5083 | 0.0058 | 0.0617 | 3.3003 | 0.3482 |
| 0.215 | 8.2359 | 0.4961 | 0.0059 | 0.0602 | 3.3793 | 0.3483 |
| 0.225 | 8.2285 | 0.4888 | 0.0061 | 0.0594 | 3.4858 | 0.3485 |
| 0.235 | 8.2252 | 0.4809 | 0.0063 | 0.0585 | 3.5825 | 0.3485 |
| 0.245 | 8.2177 | 0.4727 | 0.0064 | 0.0575 | 3.6731 | 0.3487 |
| 0.255 | 8.2104 | 0.4637 | 0.0066 | 0.0565 | 3.7518 | 0.3489 |
| 0.265 | 8.2045 | 0.46 | 0.0068 | 0.0561 | 3.869 | 0.349 |
| 0.275 | 8.2 | 0.4542 | 0.0069 | 0.0554 | 3.9661 | 0.3491 |
| 0.29 | 8.1914 | 0.4454 | 0.0072 | 0.0544 | 4.1035 | 0.3493 |
| 0.3 | 8.1866 | 0.4399 | 0.0073 | 0.0537 | 4.1943 | 0.3494 |
| 0.315 | 8.1789 | 0.4338 | 0.0076 | 0.053 | 4.3444 | 0.3495 |
| 0.325 | 8.1747 | 0.4289 | 0.0078 | 0.0525 | 4.4329 | 0.3496 |
| 0.34 | 8.168 | 0.4244 | 0.008 | 0.052 | 4.5908 | 0.3498 |
| 0.355 | 8.1556 | 0.4159 | 0.0082 | 0.051 | 4.701 | 0.3501 |
| 0.37 | 8.1537 | 0.4134 | 0.0085 | 0.0507 | 4.8706 | 0.3501 |
| 0.385 | 8.1475 | 0.408 | 0.0087 | 0.0501 | 5.0042 | 0.3502 |
| 0.405 | 8.1402 | 0.4008 | 0.009 | 0.0492 | 5.1739 | 0.3504 |
| 0.42 | 8.1352 | 0.3956 | 0.0092 | 0.0486 | 5.2974 | 0.3505 |
| 0.44 | 8.1266 | 0.3885 | 0.0095 | 0.0478 | 5.4525 | 0.3507 |
| 0.455 | 8.1228 | 0.3826 | 0.0097 | 0.0471 | 5.5539 | 0.3508 |
| 0.475 | 8.1178 | 0.3738 | 0.0099 | 0.046 | 5.6661 | 0.3509 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.495 | 8.1144 | 0.3623 | 0.01 | 0.0446 | 5.7246 | 0.351 |
| 0.52 | 8.1221 | 0.3405 | 0.0098 | 0.0419 | 5.6495 | 0.3508 |
| 0.54 | 8.1846 | 0.3557 | 0.0107 | 0.0435 | 6.1059 | 0.3495 |
| 0.565 | 8.1226 | 0.3992 | 0.0125 | 0.0491 | 7.1958 | 0.3508 |
| 0.585 | 8.1088 | 0.3868 | 0.0126 | 0.0477 | 7.2256 | 0.3511 |
| 0.61 | 8.1038 | 0.3783 | 0.0128 | 0.0467 | 7.3709 | 0.3512 |
| 0.64 | 8.102 | 0.3739 | 0.0133 | 0.0461 | 7.6442 | 0.3512 |
| 0.665 | 8.1012 | 0.3728 | 0.0138 | 0.046 | 7.9209 | 0.3512 |
| 0.695 | 8.1008 | 0.3741 | 0.0145 | 0.0462 | 8.3063 | 0.3513 |
| 0.725 | 8.1009 | 0.3787 | 0.0153 | 0.0468 | 8.7728 | 0.3512 |
| 0.755 | 8.0958 | 0.3843 | 0.0161 | 0.0475 | 9.2728 | 0.3514 |
| 0.785 | 8.0949 | 0.3886 | 0.017 | 0.048 | 9.75 | 0.3514 |
| 0.82 | 8.0898 | 0.3965 | 0.0181 | 0.049 | 10.3933 | 0.3515 |
| 0.855 | 8.0815 | 0.4041 | 0.0192 | 0.05 | 11.0512 | 0.3517 |
| 0.895 | 8.0695 | 0.4111 | 0.0205 | 0.0509 | 11.7772 | 0.3519 |
| 0.93 | 8.0577 | 0.4134 | 0.0214 | 0.0513 | 12.3139 | 0.3522 |
| 0.97 | 8.044 | 0.4103 | 0.0221 | 0.051 | 12.76 | 0.3525 |
| 1.015 | 8.0328 | 0.3958 | 0.0223 | 0.0493 | 12.8905 | 0.3527 |
| 1.055 | 8.0481 | 0.3631 | 0.0213 | 0.0451 | 12.2774 | 0.3524 |
| 1.1 | 8.1216 | 0.4458 | 0.0273 | 0.0549 | 15.6471 | 0.3508 |
| 1.15 | 8.0429 | 0.4657 | 0.0298 | 0.0579 | 17.1708 | 0.3525 |
| 1.195 | 8.0247 | 0.4519 | 0.03 | 0.0563 | 17.3342 | 0.3529 |
| 1.25 | 8.0219 | 0.4449 | 0.0309 | 0.0555 | 17.8533 | 0.3529 |
| 1.3 | 8.024 | 0.4467 | 0.0323 | 0.0557 | 18.6417 | 0.3529 |
| 1.36 | 8.0258 | 0.4567 | 0.0345 | 0.0569 | 19.9351 | 0.3528 |
| 1.415 | 8.0235 | 0.4696 | 0.0369 | 0.0585 | 21.3287 | 0.3529 |
| 1.475 | 8.0155 | 0.4824 | 0.0396 | 0.0602 | 22.8498 | 0.3531 |
| 1.54 | 8.0053 | 0.4876 | 0.0418 | 0.0609 | 24.1294 | 0.3533 |
| 1.605 | 8.0171 | 0.4821 | 0.043 | 0.0601 | 24.8435 | 0.353 |
| 1.675 | 8.0223 | 0.5407 | 0.0504 | 0.0674 | 29.0666 | 0.3529 |
| 1.745 | 7.9849 | 0.55 | 0.0534 | 0.0689 | 30.8774 | 0.3537 |
| 1.82 | 7.9709 | 0.5478 | 0.0554 | 0.0687 | 32.1019 | 0.354 |
| 1.9 | 7.9675 | 0.551 | 0.0582 | 0.0692 | 33.7178 | 0.3541 |
| 1.98 | 7.9675 | 0.5603 | 0.0617 | 0.0703 | 35.7293 | 0.3541 |
| 2.065 | 7.9666 | 0.5753 | 0.0661 | 0.0722 | 38.2611 | 0.3541 |
| 2.155 | 7.9641 | 0.5954 | 0.0713 | 0.0748 | 41.3236 | 0.3541 |
| 2.25 | 7.9538 | 0.6145 | 0.0769 | 0.0773 | 44.5623 | 0.3543 |
| 2.345 | 7.9478 | 0.6288 | 0.082 | 0.0791 | 47.5358 | 0.3544 |
| 2.445 | 7.9442 | 0.6465 | 0.0879 | 0.0814 | 50.9693 | 0.3545 |
| 2.55 | 7.9402 | 0.6685 | 0.0948 | 0.0842 | 54.9792 | 0.3546 |
| 2.66 | 7.9347 | 0.6956 | 0.1029 | 0.0877 | 59.6871 | 0.3547 |
| 2.775 | 7.9156 | 0.7246 | 0.1118 | 0.0915 | 64.9426 | 0.3551 |
| 2.89 | 7.9019 | 0.7375 | 0.1185 | 0.0933 | 68.8952 | 0.3554 |
| 3.015 | 7.8952 | 0.7597 | 0.1274 | 0.0962 | 74.0609 | 0.3555 |
| 3.145 | 7.8834 | 0.7857 | 0.1374 | 0.0997 | 79.9558 | 0.3557 |
| 3.28 | 7.8714 | 0.8098 | 0.1477 | 0.1029 | 86.0005 | 0.356 |
| 3.42 | 7.8547 | 0.8357 | 0.1589 | 0.1064 | 92.6263 | 0.3563 |
| 3.57 | 7.8403 | 0.8552 | 0.1698 | 0.1091 | 99.0358 | 0.3566 |
| 3.72 | 7.8316 | 0.8787 | 0.1818 | 0.1122 | 106.0771 | 0.3568 |
| 3.88 | 7.822 | 0.908 | 0.1959 | 0.1161 | 114.3894 | 0.357 |
| 4.045 | 7.8106 | 0.9412 | 0.2117 | 0.1205 | 123.6841 | 0.3572 |


A.P. HILL, DART , File: 16JL61059
20 deg C, Mv = 19.6%, 1.470 g/cc (dry)
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz
Real
Imaginary


A.P. HILL, DART , File: 16JL61059
20 deg C, Mv = 19.6%, 1.470 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
10
1
0.1
0.01
0.001
0.01
0.1
1
10

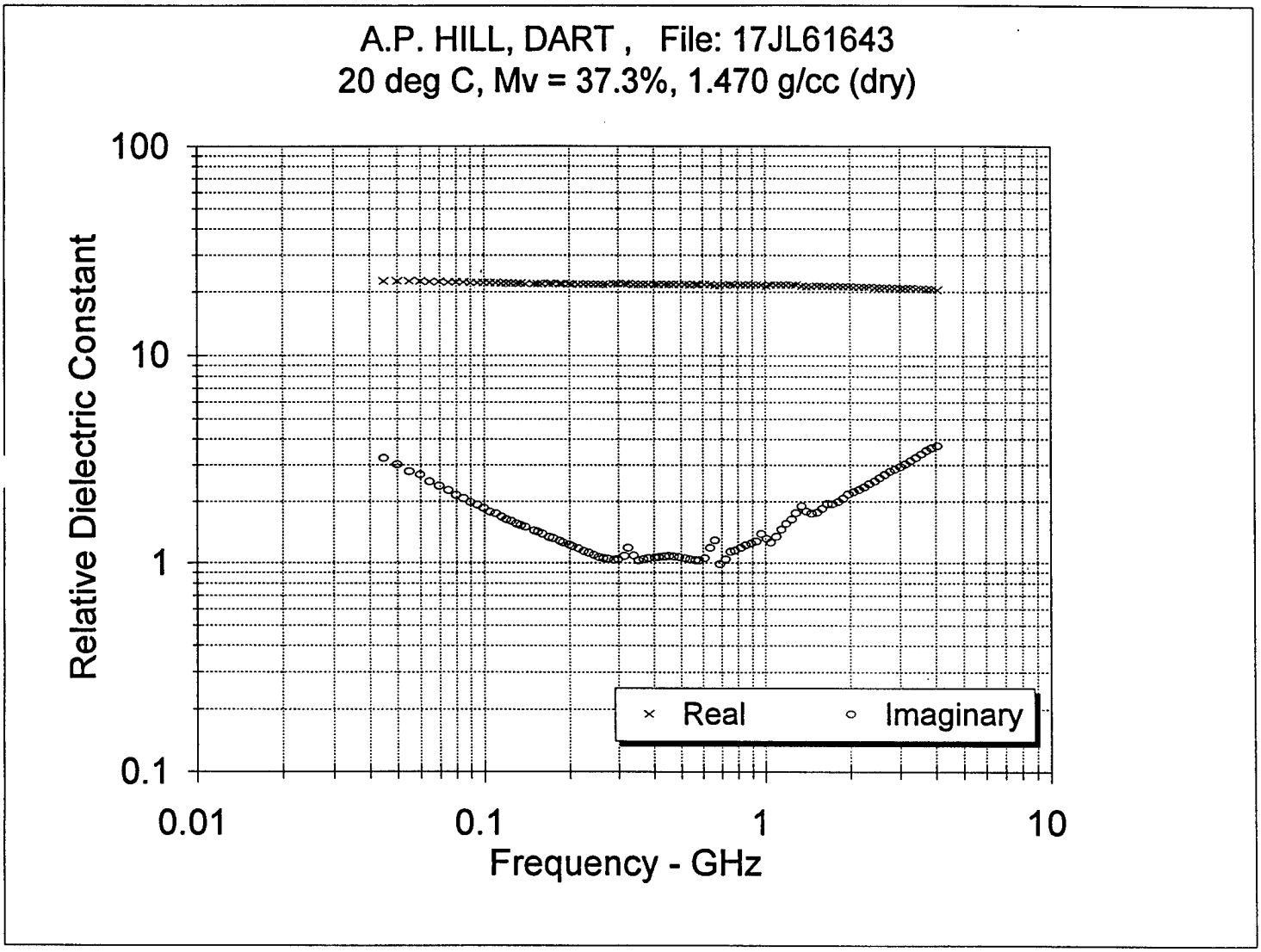

A.P. HILL, DART , File: 16JL61059
20 deg C, Mv = 19.6%, 1.470 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
1000
100
10
1
0.01
0.1
1
10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

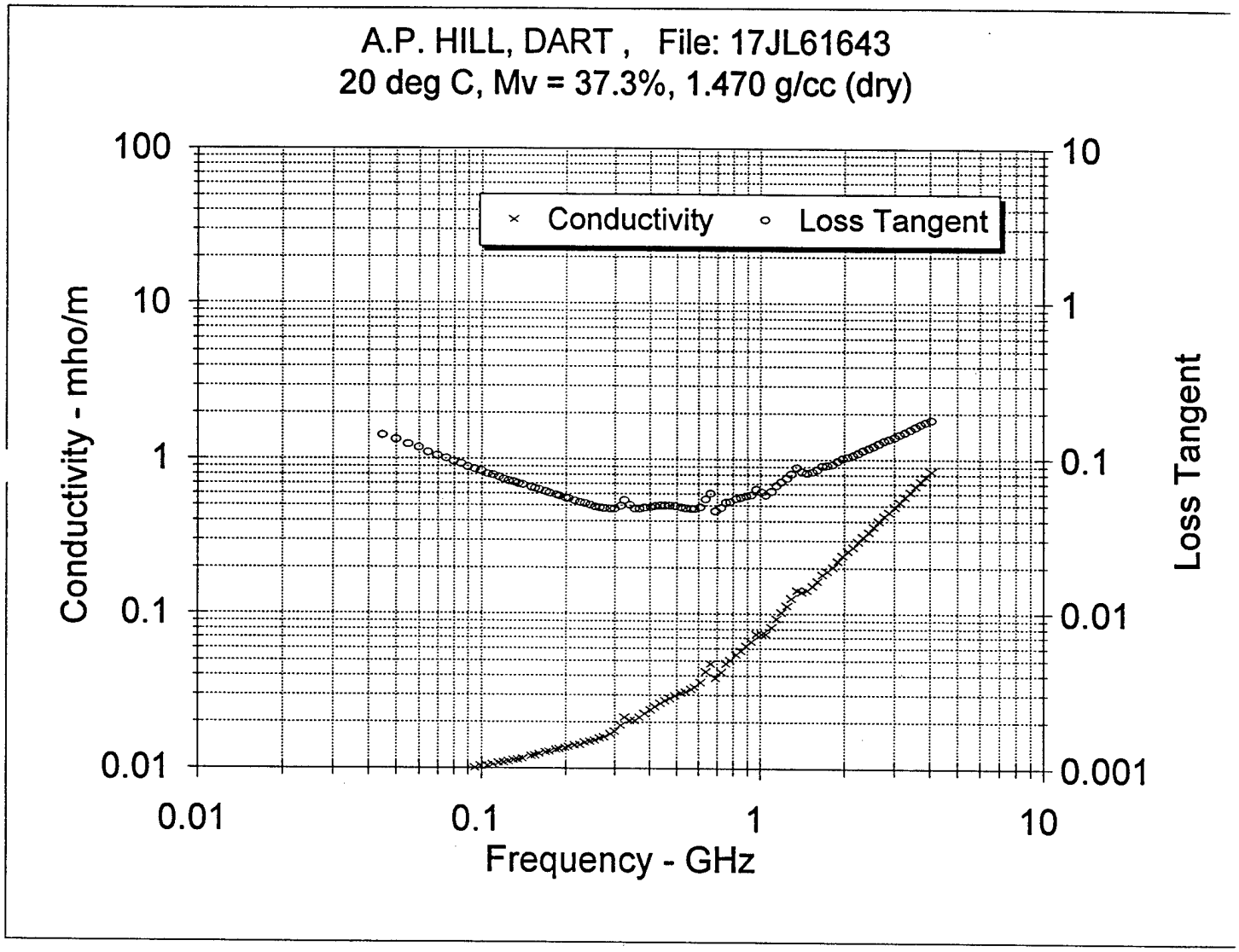
17JL61643
A.P. HILL, DART
9.7
4
37.3
20
1.47

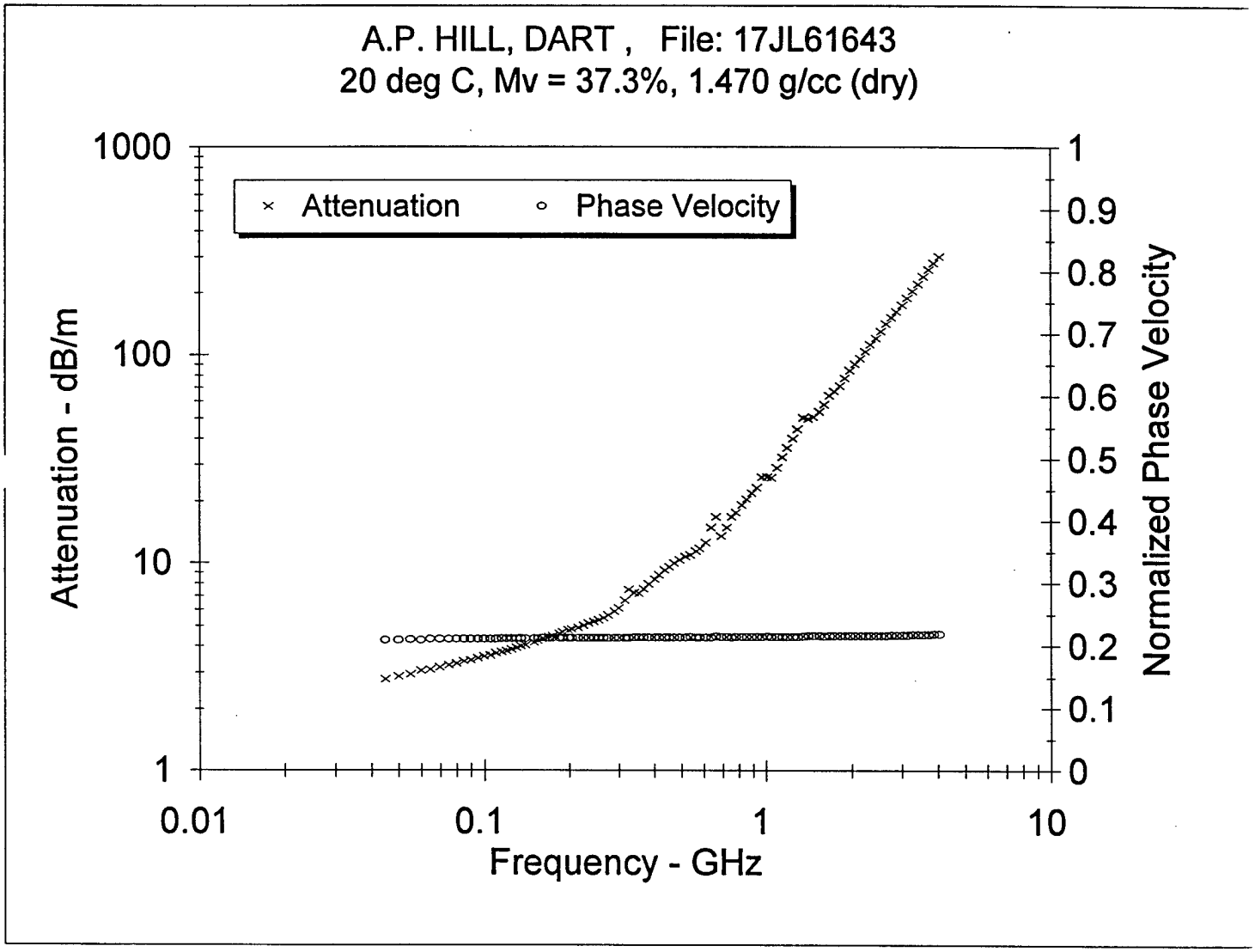
A.P. HILL, DART , File: 17JL61643
20 deg C, Mv = 37.3%, 1.470 g/cc (dry)

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.045 | 22.532 | 3.224 | 0.0081 | 0.1431 | 2.773 | 0.2101 |
| 0.05 | 22.4839 | 2.9876 | 0.0083 | 0.1329 | 2.8592 | 0.2104 |
| 0.055 | 22.4121 | 2.7851 | 0.0085 | 0.1243 | 2.9374 | 0.2108 |
| 0.06 | 22.4939 | 2.6689 | 0.0089 | 0.1187 | 3.0657 | 0.2105 |
| 0.065 | 22.3357 | 2.4758 | 0.0089 | 0.1108 | 3.0925 | 0.2113 |
| 0.07 | 22.3268 | 2.3577 | 0.0092 | 0.1056 | 3.1726 | 0.2113 |
| 0.075 | 22.2535 | 2.2478 | 0.0094 | 0.101 | 3.2465 | 0.2117 |
| 0.08 | 22.2132 | 2.136 | 0.0095 | 0.0962 | 3.2941 | 0.2119 |
| 0.085 | 22.1873 | 2.0604 | 0.0097 | 0.0929 | 3.3783 | 0.2121 |
| 0.09 | 22.1611 | 1.9788 | 0.0099 | 0.0893 | 3.4377 | 0.2122 |
| 0.095 | 22.1354 | 1.9128 | 0.0101 | 0.0864 | 3.5098 | 0.2123 |
| 0.1 | 22.0987 | 1.8511 | 0.0103 | 0.0838 | 3.5785 | 0.2125 |
| 0.105 | 22.0659 | 1.7763 | 0.0104 | 0.0805 | 3.6086 | 0.2127 |
| 0.11 | 22.0606 | 1.7399 | 0.0106 | 0.0789 | 3.7036 | 0.2127 |
| 0.115 | 22.0312 | 1.6835 | 0.0108 | 0.0764 | 3.749 | 0.2129 |
| 0.12 | 22.021 | 1.6316 | 0.0109 | 0.0741 | 3.7925 | 0.213 |
| 0.125 | 21.9986 | 1.5975 | 0.0111 | 0.0726 | 3.87 | 0.2131 |
| 0.13 | 21.9779 | 1.5588 | 0.0113 | 0.0709 | 3.9293 | 0.2132 |
| 0.135 | 21.9634 | 1.5239 | 0.0114 | 0.0694 | 3.9906 | 0.2132 |
| 0.14 | 21.9442 | 1.4954 | 0.0116 | 0.0681 | 4.0627 | 0.2133 |
| 0.15 | 21.9239 | 1.4375 | 0.012 | 0.0656 | 4.1865 | 0.2135 |
| 0.155 | 21.9126 | 1.4145 | 0.0122 | 0.0646 | 4.258 | 0.2135 |
| 0.16 | 21.9051 | 1.3898 | 0.0124 | 0.0634 | 4.3194 | 0.2136 |
| 0.17 | 21.8787 | 1.34 | 0.0127 | 0.0612 | 4.4277 | 0.2137 |
| 0.175 | 21.867 | 1.318 | 0.0128 | 0.0603 | 4.4845 | 0.2138 |
| 0.185 | 21.8506 | 1.2786 | 0.0132 | 0.0585 | 4.6009 | 0.2138 |
| 0.19 | 21.8442 | 1.2611 | 0.0133 | 0.0577 | 4.6611 | 0.2139 |
| 0.2 | 21.833 | 1.2253 | 0.0136 | 0.0561 | 4.7686 | 0.2139 |
| 0.205 | 21.8256 | 1.2086 | 0.0138 | 0.0554 | 4.8219 | 0.214 |
| 0.215 | 21.8158 | 1.1759 | 0.0141 | 0.0539 | 4.9216 | 0.214 |
| 0.225 | 21.8174 | 1.1462 | 0.0143 | 0.0525 | 5.0205 | 0.214 |
| 0.235 | 21.8139 | 1.1243 | 0.0147 | 0.0515 | 5.1437 | 0.214 |
| 0.245 | 21.8135 | 1.0948 | 0.0149 | 0.0502 | 5.2219 | 0.214 |
| 0.255 | 21.8231 | 1.0735 | 0.0152 | 0.0492 | 5.3285 | 0.214 |
| 0.265 | 21.8189 | 1.0574 | 0.0156 | 0.0485 | 5.4551 | 0.214 |
| 0.275 | 21.8291 | 1.0488 | 0.016 | 0.048 | 5.6134 | 0.214 |
| 0.29 | 21.8461 | 1.0396 | 0.0168 | 0.0476 | 5.8656 | 0.2139 |
| 0.3 | 21.8582 | 1.0436 | 0.0174 | 0.0477 | 6.0896 | 0.2138 |
| 0.315 | 21.8855 | 1.0832 | 0.019 | 0.0495 | 6.6322 | 0.2137 |
| 0.325 | 21.8617 | 1.1813 | 0.0213 | 0.054 | 7.4661 | 0.2138 |
| 0.34 | 21.6815 | 1.0853 | 0.0205 | 0.0501 | 7.2057 | 0.2147 |
| 0.355 | 21.7335 | 1.0313 | 0.0204 | 0.0475 | 7.1409 | 0.2144 |
| 0.37 | 21.7532 | 1.0416 | 0.0214 | 0.0479 | 7.514 | 0.2143 |
| 0.385 | 21.7459 | 1.0527 | 0.0225 | 0.0484 | 7.9032 | 0.2144 |
| 0.405 | 21.7294 | 1.0643 | 0.024 | 0.049 | 8.4086 | 0.2145 |
| 0.42 | 21.7123 | 1.0719 | 0.025 | 0.0494 | 8.7852 | 0.2145 |
| 0.44 | 21.6846 | 1.0781 | 0.0264 | 0.0497 | 9.2631 | 0.2147 |
| 0.455 | 21.666 | 1.0809 | 0.0273 | 0.0499 | 9.6072 | 0.2148 |
| 0.475 | 21.6438 | 1.076 | 0.0284 | 0.0497 | 9.9894 | 0.2149 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.495 | 21.6247 | 1.0707 | 0.0295 | 0.0495 | 10.3632 | 0.215 |
| 0.52 | 21.6127 | 1.0562 | 0.0305 | 0.0489 | 10.743 | 0.215 |
| 0.54 | 21.6064 | 1.0429 | 0.0313 | 0.0483 | 11.0173 | 0.2151 |
| 0.565 | 21.6147 | 1.0315 | 0.0324 | 0.0477 | 11.3984 | 0.215 |
| 0.585 | 21.6322 | 1.0299 | 0.0335 | 0.0476 | 11.7791 | 0.2149 |
| 0.61 | 21.6653 | 1.0554 | 0.0358 | 0.0487 | 12.5772 | 0.2148 |
| 0.64 | 21.6884 | 1.1904 | 0.0424 | 0.0549 | 14.8749 | 0.2146 |
| 0.665 | 21.418 | 1.2911 | 0.0477 | 0.0603 | 16.8666 | 0.216 |
| 0.695 | 21.4741 | 0.9924 | 0.0384 | 0.0462 | 13.5345 | 0.2157 |
| 0.725 | 21.5804 | 1.0448 | 0.0421 | 0.0484 | 14.8275 | 0.2152 |
| 0.755 | 21.6162 | 1.132 | 0.0475 | 0.0524 | 16.7142 | 0.215 |
| 0.785 | 21.6024 | 1.1496 | 0.0502 | 0.0532 | 17.6549 | 0.2151 |
| 0.82 | 21.5833 | 1.1908 | 0.0543 | 0.0552 | 19.1112 | 0.2152 |
| 0.855 | 21.5618 | 1.2192 | 0.058 | 0.0565 | 20.4108 | 0.2153 |
| 0.895 | 21.5491 | 1.242 | 0.0618 | 0.0576 | 21.7725 | 0.2153 |
| 0.93 | 21.5588 | 1.2724 | 0.0658 | 0.059 | 23.1715 | 0.2153 |
| 0.97 | 21.5482 | 1.3783 | 0.0743 | 0.064 | 26.1846 | 0.2153 |
| 1.015 | 21.3692 | 1.308 | 0.0738 | 0.0612 | 26.1098 | 0.2162 |
| 1.055 | 21.5139 | 1.2582 | 0.0738 | 0.0585 | 26.0202 | 0.2155 |
| 1.1 | 21.5814 | 1.3476 | 0.0824 | 0.0624 | 29.0099 | 0.2152 |
| 1.15 | 21.5952 | 1.4577 | 0.0932 | 0.0675 | 32.7928 | 0.2151 |
| 1.195 | 21.5777 | 1.5467 | 0.1028 | 0.0717 | 36.1694 | 0.2151 |
| 1.25 | 21.5488 | 1.6345 | 0.1136 | 0.0759 | 40.0052 | 0.2153 |
| 1.3 | 21.5426 | 1.7495 | 0.1265 | 0.0812 | 44.5342 | 0.2153 |
| 1.36 | 21.3187 | 1.8826 | 0.1424 | 0.0883 | 50.3896 | 0.2164 |
| 1.415 | 21.2192 | 1.7774 | 0.1399 | 0.0838 | 49.619 | 0.2169 |
| 1.475 | 21.2465 | 1.74 | 0.1427 | 0.0819 | 50.6021 | 0.2168 |
| 1.54 | 21.2779 | 1.7663 | 0.1513 | 0.083 | 53.5909 | 0.2166 |
| 1.605 | 21.2935 | 1.8378 | 0.164 | 0.0863 | 58.0882 | 0.2165 |
| 1.675 | 21.2423 | 1.9319 | 0.1799 | 0.0909 | 63.7977 | 0.2167 |
| 1.745 | 21.2019 | 1.9406 | 0.1883 | 0.0915 | 66.8251 | 0.2169 |
| 1.82 | 21.2099 | 1.9841 | 0.2008 | 0.0935 | 71.2406 | 0.2169 |
| 1.9 | 21.2086 | 2.0635 | 0.218 | 0.0973 | 77.3446 | 0.2169 |
| 1.98 | 21.1806 | 2.154 | 0.2372 | 0.1017 | 84.182 | 0.217 |
| 2.065 | 21.1211 | 2.2149 | 0.2543 | 0.1049 | 90.399 | 0.2173 |
| 2.155 | 21.1035 | 2.2602 | 0.2708 | 0.1071 | 96.3039 | 0.2174 |
| 2.25 | 21.0888 | 2.3329 | 0.2919 | 0.1106 | 103.8072 | 0.2174 |
| 2.345 | 21.0632 | 2.4188 | 0.3154 | 0.1148 | 112.229 | 0.2175 |
| 2.445 | 21.0291 | 2.4933 | 0.339 | 0.1186 | 120.7036 | 0.2177 |
| 2.55 | 21.0066 | 2.5825 | 0.3662 | 0.1229 | 130.4445 | 0.2178 |
| 2.66 | 20.9641 | 2.6849 | 0.3971 | 0.1281 | 141.5903 | 0.218 |
| 2.775 | 20.9059 | 2.769 | 0.4273 | 0.1324 | 152.5259 | 0.2182 |
| 2.89 | 20.8693 | 2.8389 | 0.4562 | 0.136 | 162.9829 | 0.2184 |
| 3.015 | 20.8393 | 2.9258 | 0.4905 | 0.1404 | 175.3351 | 0.2185 |
| 3.145 | 20.8055 | 3.0255 | 0.5291 | 0.1454 | 189.2503 | 0.2187 |
| 3.28 | 20.768 | 3.1341 | 0.5716 | 0.1509 | 204.5985 | 0.2188 |
| 3.42 | 20.7244 | 3.2493 | 0.6179 | 0.1568 | 221.3608 | 0.219 |
| 3.57 | 20.6693 | 3.3746 | 0.6699 | 0.1633 | 240.2341 | 0.2192 |
| 3.72 | 20.6029 | 3.4916 | 0.7223 | 0.1695 | 259.3598 | 0.2195 |
| 3.88 | 20.5363 | 3.602 | 0.7771 | 0.1754 | 279.4477 | 0.2198 |
| 4.045 | 20.4813 | 3.7143 | 0.8354 | 0.1814 | 300.7429 | 0.2201 |


A.P. HILL, DART , File: 17JL61643
20 deg C, Mv = 37.3%, 1.470 g/cc (dry)
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz
Real
Imaginary


A.P. HILL, DART , File: 17JL61643
20 deg C, Mv = 37.3%, 1.470 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
100
10
1
0.1
0.01
10
1
0.1
0.01
0.001
0.01
0.1
1
10

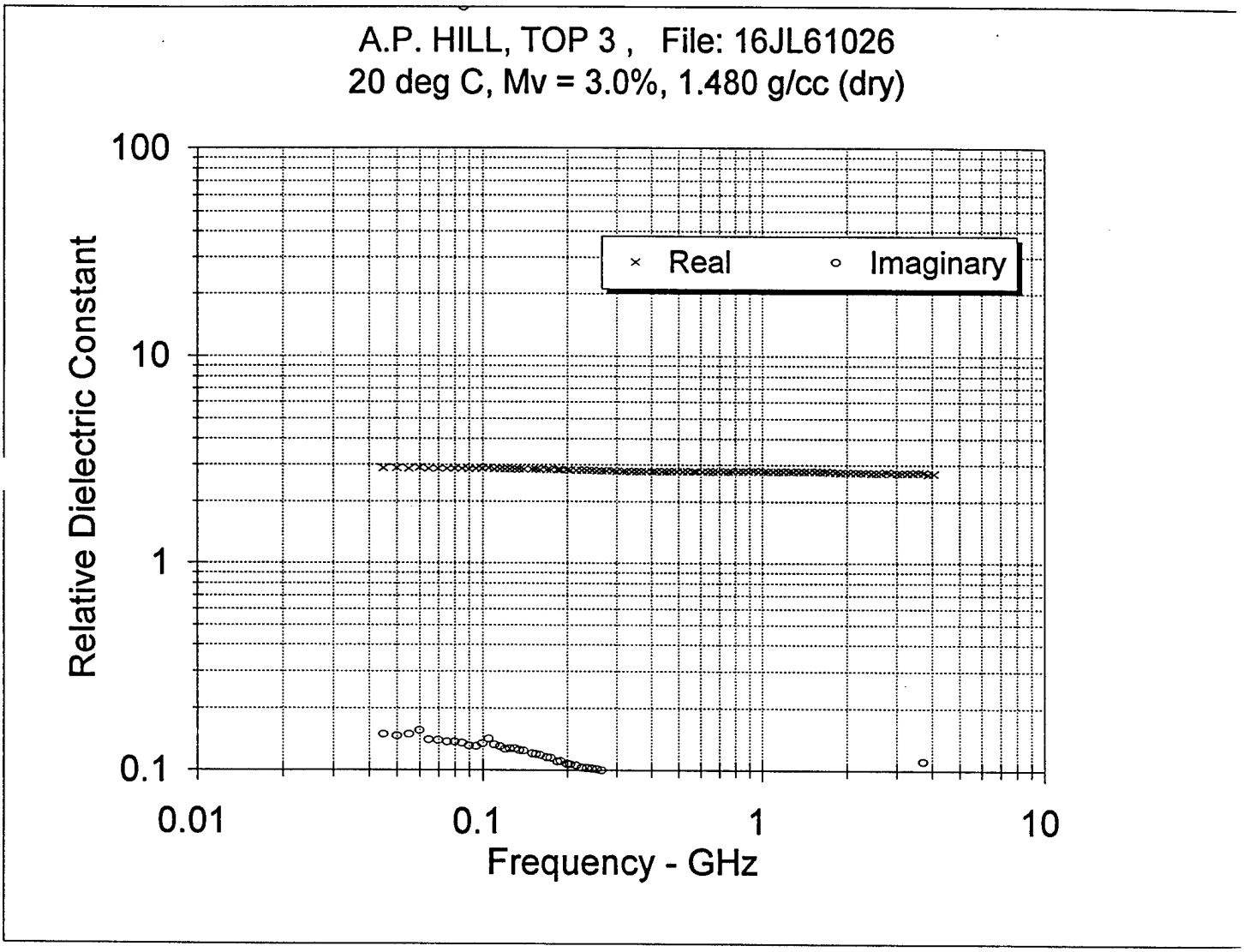

A.P. HILL, DART , File: 17JL61643
20 deg C, Mv = 37.3%, 1.470 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
1000
100
10
1
0.01
0.1
1
10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

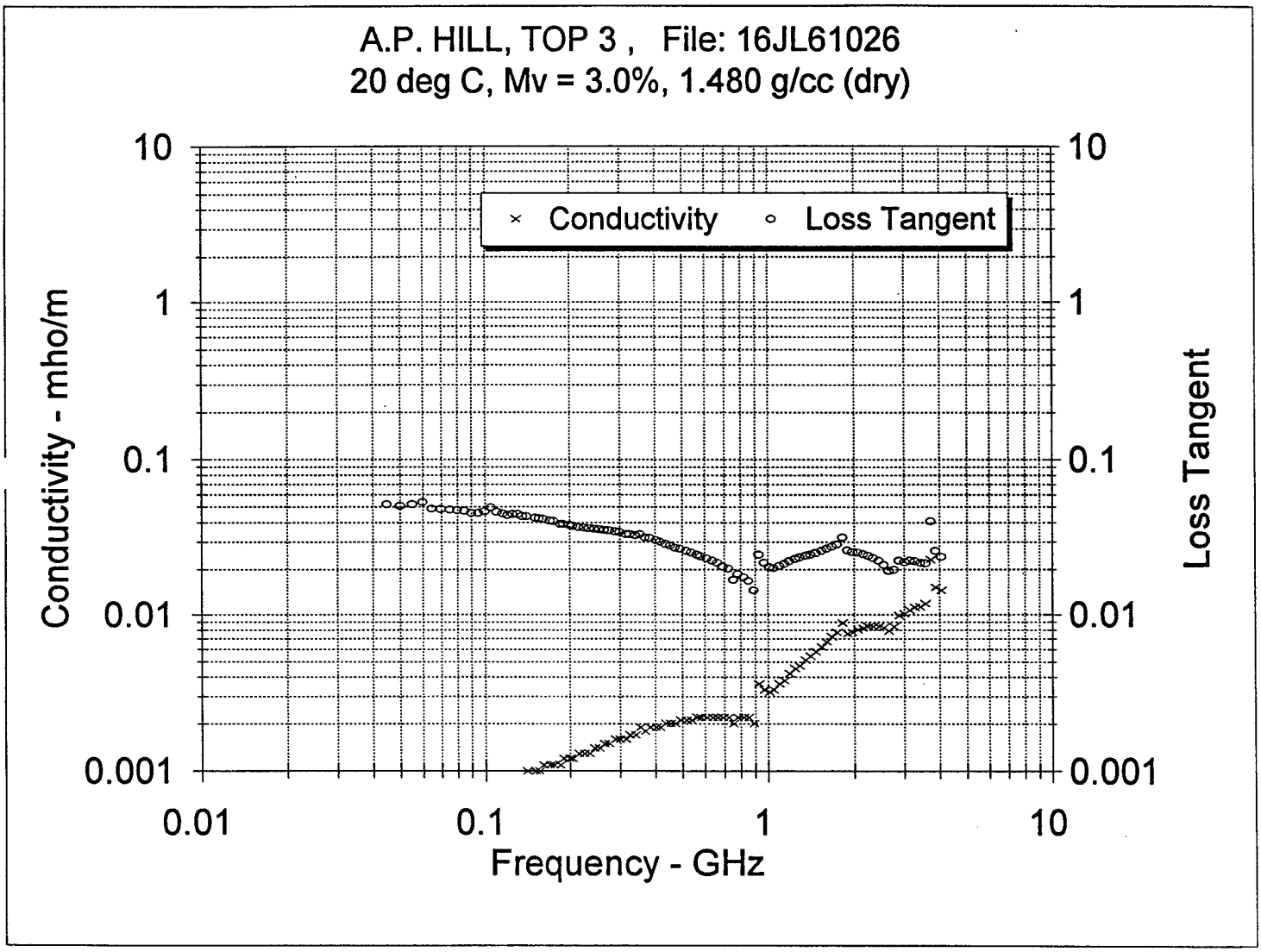
16JL61026
A.P. HILL, TOP 3
9.7
2
3
20
1.48

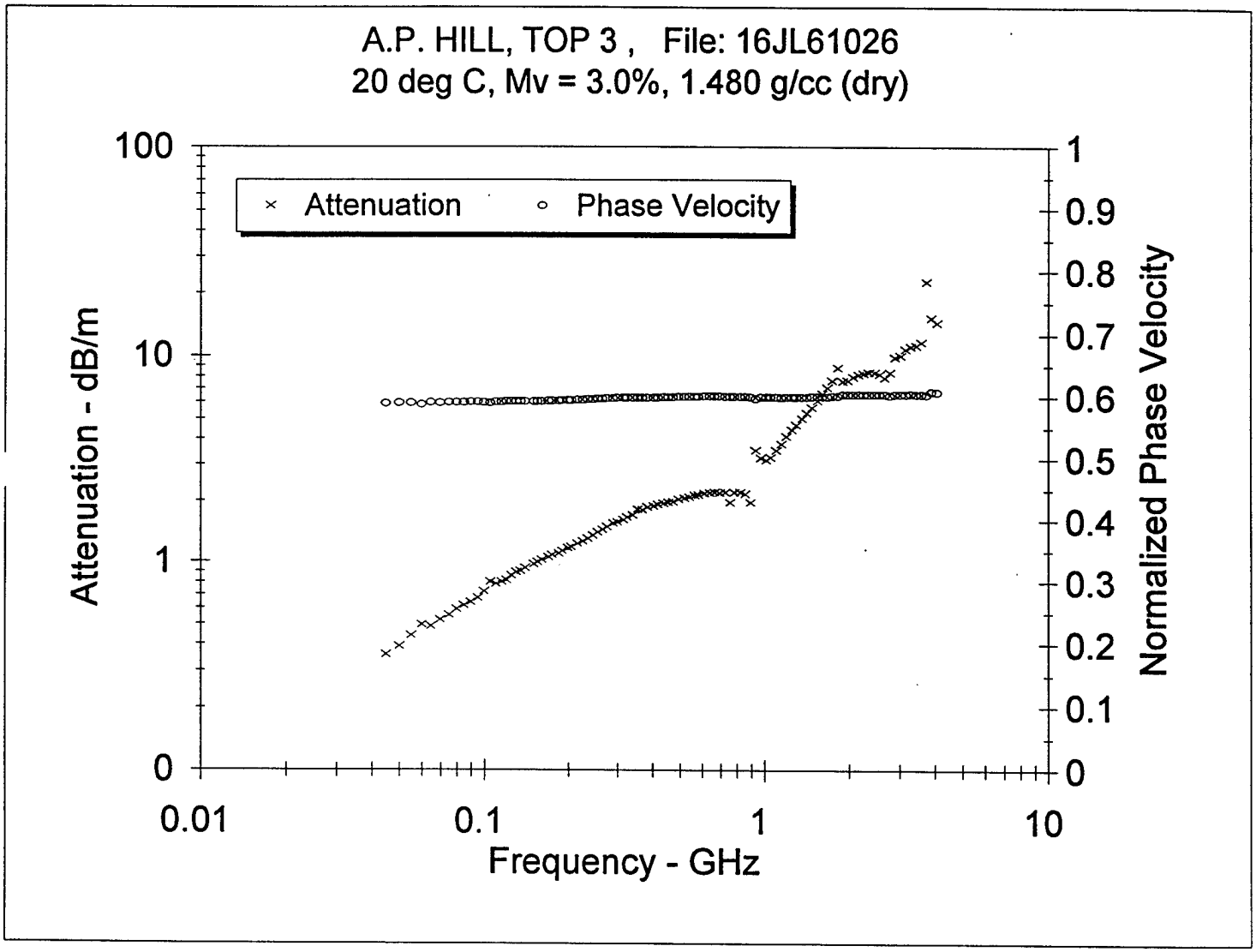
A.P. HILL, TOP 3 , File: 16JL61026
20 deg C, Mv = 3.0%, 1.480 g/cc (dry)

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.045 | 2.8709 | 0.1486 | 0.0004 | 0.0518 | 0.3588 | 0.59 |
| 0.05 | 2.8674 | 0.1457 | 0.0004 | 0.0508 | 0.3912 | 0.5904 |
| 0.055 | 2.8623 | 0.1486 | 0.0005 | 0.0519 | 0.4394 | 0.5909 |
| 0.06 | 2.8877 | 0.155 | 0.0005 | 0.0537 | 0.4977 | 0.5883 |
| 0.065 | 2.8613 | 0.1399 | 0.0005 | 0.0489 | 0.4887 | 0.591 |
| 0.07 | 2.8621 | 0.1389 | 0.0005 | 0.0485 | 0.5227 | 0.5909 |
| 0.075 | 2.8573 | 0.1371 | 0.0006 | 0.048 | 0.5533 | 0.5914 |
| 0.08 | 2.856 | 0.1366 | 0.0006 | 0.0478 | 0.5879 | 0.5916 |
| 0.085 | 2.8557 | 0.1347 | 0.0006 | 0.0472 | 0.6161 | 0.5916 |
| 0.09 | 2.8491 | 0.1312 | 0.0007 | 0.046 | 0.636 | 0.5923 |
| 0.095 | 2.8539 | 0.131 | 0.0007 | 0.0459 | 0.6699 | 0.5918 |
| 0.1 | 2.856 | 0.1338 | 0.0007 | 0.0469 | 0.7202 | 0.5916 |
| 0.105 | 2.8684 | 0.1421 | 0.0008 | 0.0496 | 0.8013 | 0.5903 |
| 0.11 | 2.8495 | 0.1324 | 0.0008 | 0.0465 | 0.7847 | 0.5922 |
| 0.115 | 2.8478 | 0.1298 | 0.0008 | 0.0456 | 0.8044 | 0.5924 |
| 0.12 | 2.8475 | 0.1264 | 0.0008 | 0.0444 | 0.8172 | 0.5925 |
| 0.125 | 2.8457 | 0.1274 | 0.0009 | 0.0448 | 0.8588 | 0.5926 |
| 0.13 | 2.8416 | 0.1276 | 0.0009 | 0.0449 | 0.8946 | 0.5931 |
| 0.135 | 2.8423 | 0.1244 | 0.0009 | 0.0438 | 0.9058 | 0.593 |
| 0.14 | 2.8416 | 0.1238 | 0.001 | 0.0436 | 0.9353 | 0.5931 |
| 0.15 | 2.8385 | 0.1202 | 0.001 | 0.0424 | 0.9735 | 0.5934 |
| 0.155 | 2.836 | 0.1196 | 0.001 | 0.0422 | 1.0012 | 0.5937 |
| 0.16 | 2.8343 | 0.1186 | 0.0011 | 0.0418 | 1.0248 | 0.5939 |
| 0.17 | 2.8312 | 0.1154 | 0.0011 | 0.0408 | 1.0607 | 0.5942 |
| 0.175 | 2.8291 | 0.1146 | 0.0011 | 0.0405 | 1.0843 | 0.5944 |
| 0.185 | 2.8264 | 0.1102 | 0.0011 | 0.039 | 1.103 | 0.5947 |
| 0.19 | 2.8255 | 0.1104 | 0.0012 | 0.0391 | 1.1343 | 0.5948 |
| 0.2 | 2.8219 | 0.1081 | 0.0012 | 0.0383 | 1.1705 | 0.5952 |
| 0.205 | 2.8203 | 0.107 | 0.0012 | 0.0379 | 1.1874 | 0.5953 |
| 0.215 | 2.8177 | 0.1055 | 0.0013 | 0.0374 | 1.2288 | 0.5956 |
| 0.225 | 2.8147 | 0.1035 | 0.0013 | 0.0368 | 1.2627 | 0.596 |
| 0.235 | 2.8098 | 0.1024 | 0.0013 | 0.0365 | 1.306 | 0.5965 |
| 0.245 | 2.8087 | 0.1019 | 0.0014 | 0.0363 | 1.355 | 0.5966 |
| 0.255 | 2.8032 | 0.1011 | 0.0014 | 0.036 | 1.3997 | 0.5972 |
| 0.265 | 2.8001 | 0.1003 | 0.0015 | 0.0358 | 1.4451 | 0.5975 |
| 0.275 | 2.7965 | 0.0994 | 0.0015 | 0.0356 | 1.4869 | 0.5979 |
| 0.29 | 2.7925 | 0.0979 | 0.0016 | 0.035 | 1.5445 | 0.5983 |
| 0.3 | 2.7901 | 0.0963 | 0.0016 | 0.0345 | 1.5723 | 0.5986 |
| 0.315 | 2.783 | 0.0933 | 0.0016 | 0.0335 | 1.6024 | 0.5994 |
| 0.325 | 2.7855 | 0.0933 | 0.0017 | 0.0335 | 1.6522 | 0.5991 |
| 0.34 | 2.785 | 0.0917 | 0.0017 | 0.0329 | 1.6997 | 0.5991 |
| 0.355 | 2.7862 | 0.0938 | 0.0019 | 0.0337 | 1.8138 | 0.599 |
| 0.37 | 2.7806 | 0.0891 | 0.0018 | 0.032 | 1.7974 | 0.5996 |
| 0.385 | 2.7803 | 0.0884 | 0.0019 | 0.0318 | 1.8556 | 0.5997 |
| 0.405 | 2.7785 | 0.085 | 0.0019 | 0.0306 | 1.8787 | 0.5999 |
| 0.42 | 2.7775 | 0.0834 | 0.0019 | 0.03 | 1.9121 | 0.6 |
| 0.44 | 2.7753 | 0.0806 | 0.002 | 0.029 | 1.9362 | 0.6002 |
| 0.455 | 2.7742 | 0.0785 | 0.002 | 0.0283 | 1.9509 | 0.6003 |
| 0.475 | 2.7723 | 0.0762 | 0.002 | 0.0275 | 1.9772 | 0.6005 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.495 | 2.7703 | 0.0749 | 0.0021 | 0.027 | 2.0259 | 0.6008 |
| 0.52 | 2.7681 | 0.0723 | 0.0021 | 0.0261 | 2.0559 | 0.601 |
| 0.54 | 2.7666 | 0.0706 | 0.0021 | 0.0255 | 2.0855 | 0.6012 |
| 0.565 | 2.7643 | 0.0684 | 0.0022 | 0.0248 | 2.1156 | 0.6014 |
| 0.585 | 2.7636 | 0.0666 | 0.0022 | 0.0241 | 2.1318 | 0.6015 |
| 0.61 | 2.7629 | 0.065 | 0.0022 | 0.0235 | 2.1702 | 0.6016 |
| 0.64 | 2.7631 | 0.0624 | 0.0022 | 0.0226 | 2.1857 | 0.6016 |
| 0.665 | 2.763 | 0.0602 | 0.0022 | 0.0218 | 2.1906 | 0.6016 |
| 0.695 | 2.763 | 0.0573 | 0.0022 | 0.0207 | 2.179 | 0.6016 |
| 0.725 | 2.7637 | 0.0556 | 0.0022 | 0.0201 | 2.2035 | 0.6015 |
| 0.755 | 2.7684 | 0.0474 | 0.002 | 0.0171 | 1.9569 | 0.601 |
| 0.785 | 2.7638 | 0.0511 | 0.0022 | 0.0185 | 2.1936 | 0.6015 |
| 0.82 | 2.7646 | 0.049 | 0.0022 | 0.0177 | 2.1986 | 0.6014 |
| 0.855 | 2.7664 | 0.0463 | 0.0022 | 0.0167 | 2.1641 | 0.6012 |
| 0.895 | 2.7716 | 0.0402 | 0.002 | 0.0145 | 1.9651 | 0.6007 |
| 0.93 | 2.8034 | 0.0692 | 0.0036 | 0.0247 | 3.4936 | 0.5972 |
| 0.97 | 2.7726 | 0.0607 | 0.0033 | 0.0219 | 3.216 | 0.6005 |
| 1.015 | 2.7729 | 0.0568 | 0.0032 | 0.0205 | 3.1509 | 0.6005 |
| 1.055 | 2.7747 | 0.0563 | 0.0033 | 0.0203 | 3.2416 | 0.6003 |
| 1.1 | 2.7768 | 0.0582 | 0.0036 | 0.021 | 3.4953 | 0.6001 |
| 1.15 | 2.7771 | 0.0601 | 0.0038 | 0.0216 | 3.7717 | 0.6 |
| 1.195 | 2.7765 | 0.0626 | 0.0042 | 0.0225 | 4.08 | 0.6001 |
| 1.25 | 2.7743 | 0.0643 | 0.0045 | 0.0232 | 4.3891 | 0.6003 |
| 1.3 | 2.773 | 0.0656 | 0.0047 | 0.0237 | 4.6612 | 0.6005 |
| 1.36 | 2.7725 | 0.0673 | 0.0051 | 0.0243 | 4.9972 | 0.6005 |
| 1.415 | 2.7719 | 0.0687 | 0.0054 | 0.0248 | 5.3127 | 0.6006 |
| 1.475 | 2.7701 | 0.0701 | 0.0058 | 0.0253 | 5.6523 | 0.6008 |
| 1.54 | 2.7681 | 0.0726 | 0.0062 | 0.0262 | 6.1081 | 0.601 |
| 1.605 | 2.7665 | 0.075 | 0.0067 | 0.0271 | 6.5848 | 0.6012 |
| 1.675 | 2.7636 | 0.0771 | 0.0072 | 0.0279 | 7.0654 | 0.6015 |
| 1.745 | 2.7607 | 0.0798 | 0.0077 | 0.0289 | 7.6182 | 0.6018 |
| 1.82 | 2.7571 | 0.0881 | 0.0089 | 0.0319 | 8.7775 | 0.6022 |
| 1.9 | 2.7349 | 0.0722 | 0.0076 | 0.0264 | 7.5395 | 0.6046 |
| 1.98 | 2.7418 | 0.0702 | 0.0077 | 0.0256 | 7.6365 | 0.6039 |
| 2.065 | 2.7415 | 0.0699 | 0.008 | 0.0255 | 7.9234 | 0.6039 |
| 2.155 | 2.7393 | 0.0685 | 0.0082 | 0.025 | 8.1086 | 0.6042 |
| 2.25 | 2.7376 | 0.0668 | 0.0084 | 0.0244 | 8.263 | 0.6043 |
| 2.345 | 2.7352 | 0.0646 | 0.0084 | 0.0236 | 8.3246 | 0.6046 |
| 2.445 | 2.7334 | 0.0619 | 0.0084 | 0.0226 | 8.3196 | 0.6048 |
| 2.55 | 2.7321 | 0.0582 | 0.0083 | 0.0213 | 8.1666 | 0.605 |
| 2.66 | 2.7341 | 0.0534 | 0.0079 | 0.0195 | 7.8127 | 0.6047 |
| 2.775 | 2.7503 | 0.0546 | 0.0084 | 0.0199 | 8.3132 | 0.603 |
| 2.89 | 2.7316 | 0.0618 | 0.0099 | 0.0226 | 9.8289 | 0.605 |
| 3.015 | 2.7333 | 0.0606 | 0.0102 | 0.0222 | 10.0504 | 0.6048 |
| 3.145 | 2.7313 | 0.062 | 0.0108 | 0.0227 | 10.7375 | 0.605 |
| 3.28 | 2.7288 | 0.0613 | 0.0112 | 0.0225 | 11.0762 | 0.6053 |
| 3.42 | 2.7295 | 0.0595 | 0.0113 | 0.0218 | 11.1968 | 0.6052 |
| 3.57 | 2.7392 | 0.0595 | 0.0118 | 0.0217 | 11.6692 | 0.6042 |
| 3.72 | 2.7444 | 0.1109 | 0.0229 | 0.0404 | 22.6461 | 0.6035 |
| 3.88 | 2.6958 | 0.0706 | 0.0152 | 0.0262 | 15.1806 | 0.609 |
| 4.045 | 2.7066 | 0.0646 | 0.0145 | 0.0239 | 14.4552 | 0.6078 |


A.P. HILL, TOP 3 , File: 16JL61026
20 deg C, Mv = 3.0%, 1.480 g/cc (dry)
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz
Real
Imaginary


A.P. HILL, TOP 3 , File: 16JL61026
20 deg C, Mv = 3.0%, 1.480 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
10
1
0.1
0.01
0.001
0.01
0.1
1
10


A.P. HILL, TOP 3 , File: 16JL61026
20 deg C, Mv = 3.0%, 1.480 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
100
10
1
0
0.01
0.1
1
10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

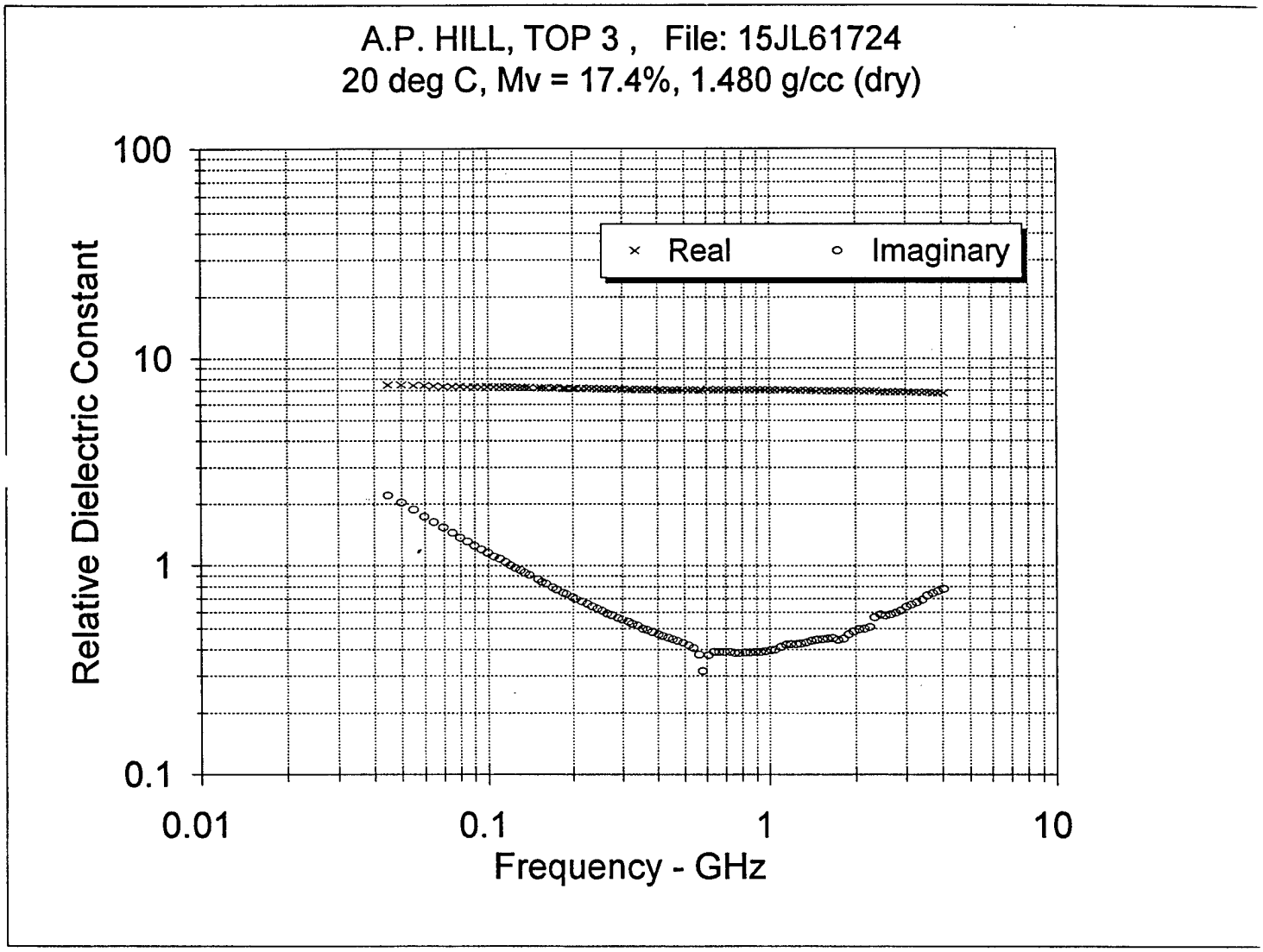
15JL61724
A.P. HILL, TOP 3

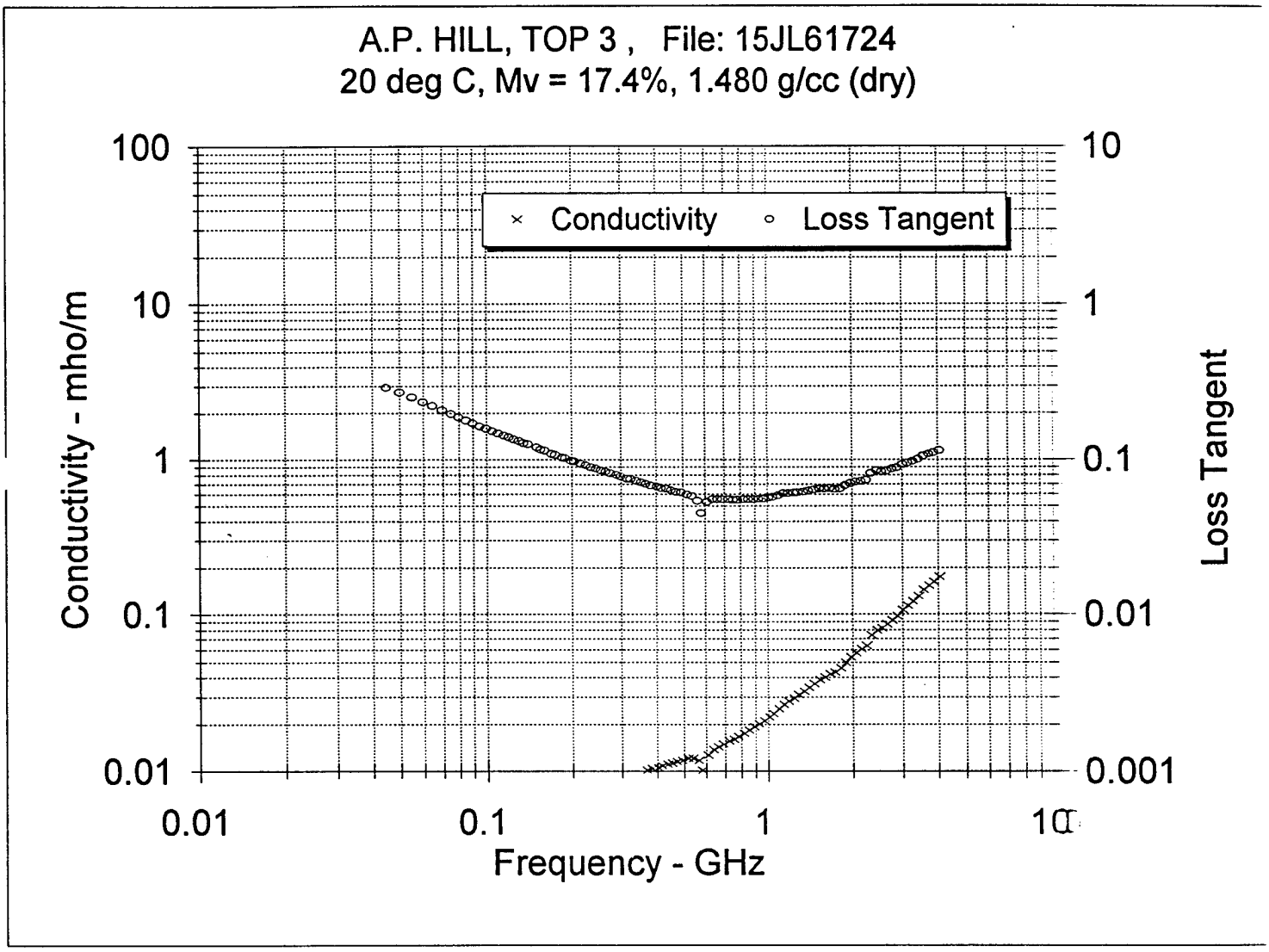
9.7
2
17.4
20
1.48

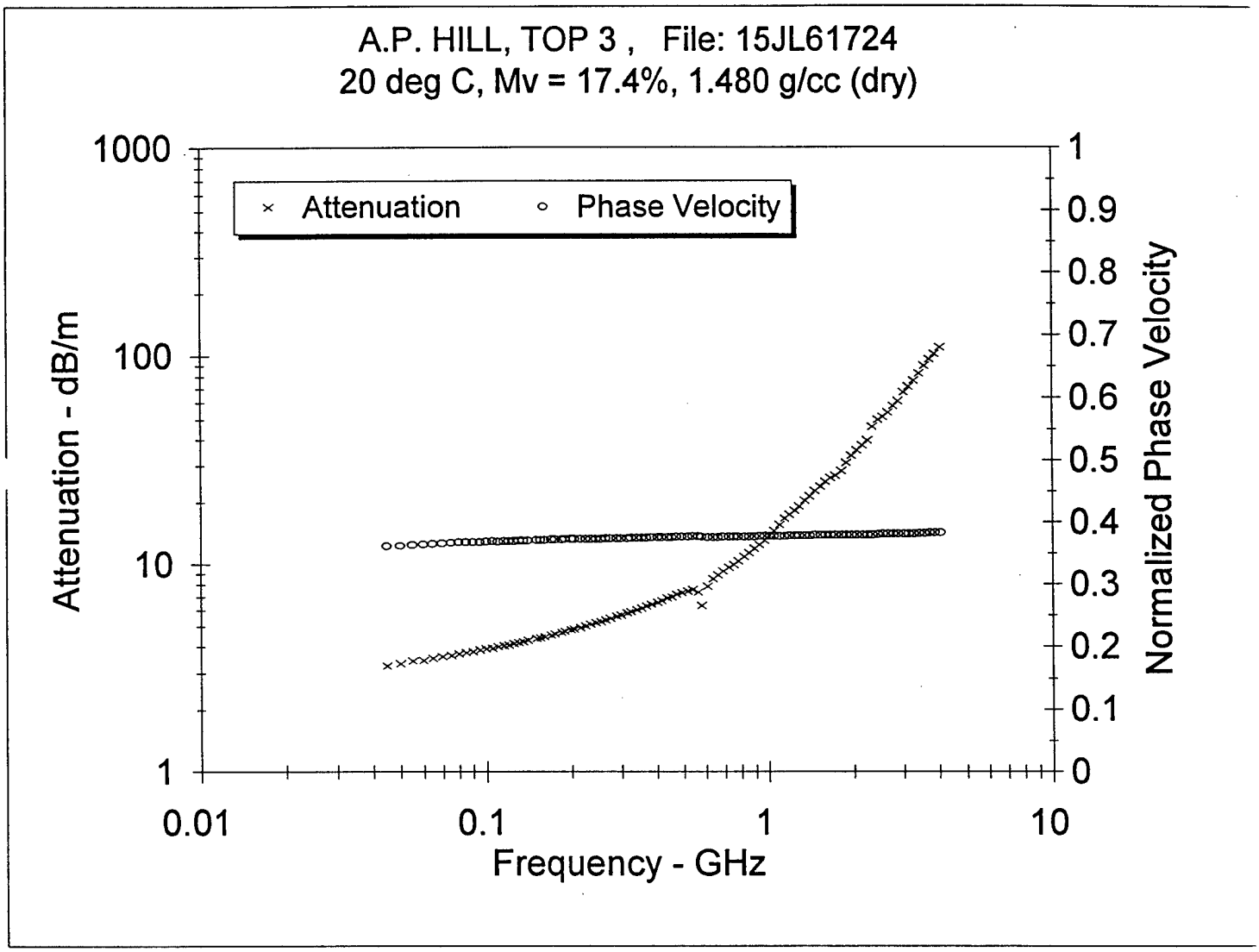
A.P. HILL, TOP 3 , File: 15JL61724
20 deg C, Mv = 17.4%, 1.480 g/cc (dry)

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.045 | 7.4504 | 2.1877 | 0.0055 | 0.2936 | 3.2465 | 0.3626 |
| 0.05 | 7.4187 | 2.0132 | 0.0056 | 0.2714 | 3.3316 | 0.3639 |
| 0.055 | 7.3845 | 1.869 | 0.0057 | 0.2531 | 3.414 | 0.3651 |
| 0.06 | 7.3756 | 1.731 | 0.0058 | 0.2347 | 3.4551 | 0.3657 |
| 0.065 | 7.3477 | 1.6295 | 0.0059 | 0.2218 | 3.5328 | 0.3667 |
| 0.07 | 7.3339 | 1.5362 | 0.006 | 0.2095 | 3.5922 | 0.3673 |
| 0.075 | 7.3138 | 1.4502 | 0.006 | 0.1983 | 3.6406 | 0.368 |
| 0.08 | 7.2979 | 1.377 | 0.0061 | 0.1887 | 3.693 | 0.3685 |
| 0.085 | 7.2893 | 1.3129 | 0.0062 | 0.1801 | 3.7446 | 0.3689 |
| 0.09 | 7.2757 | 1.2538 | 0.0063 | 0.1723 | 3.7914 | 0.3694 |
| 0.095 | 7.268 | 1.2022 | 0.0064 | 0.1654 | 3.8403 | 0.3697 |
| 0.1 | 7.2575 | 1.1596 | 0.0064 | 0.1598 | 3.9028 | 0.37 |
| 0.105 | 7.2369 | 1.1078 | 0.0065 | 0.1531 | 3.9214 | 0.3707 |
| 0.11 | 7.2395 | 1.0796 | 0.0066 | 0.1491 | 4.0034 | 0.3706 |
| 0.115 | 7.2303 | 1.0429 | 0.0067 | 0.1442 | 4.0465 | 0.3709 |
| 0.12 | 7.2264 | 1.0082 | 0.0067 | 0.1395 | 4.0838 | 0.3711 |
| 0.125 | 7.2146 | 0.9804 | 0.0068 | 0.1359 | 4.1406 | 0.3714 |
| 0.13 | 7.2078 | 0.9534 | 0.0069 | 0.1323 | 4.19 | 0.3717 |
| 0.135 | 7.1999 | 0.9257 | 0.0069 | 0.1286 | 4.2275 | 0.3719 |
| 0.14 | 7.1964 | 0.9045 | 0.007 | 0.1257 | 4.2851 | 0.372 |
| 0.15 | 7.1844 | 0.8603 | 0.0072 | 0.1198 | 4.3716 | 0.3724 |
| 0.155 | 7.1776 | 0.8396 | 0.0072 | 0.117 | 4.4106 | 0.3726 |
| 0.16 | 7.1709 | 0.8216 | 0.0073 | 0.1146 | 4.4581 | 0.3728 |
| 0.17 | 7.1605 | 0.7879 | 0.0074 | 0.11 | 4.5458 | 0.3731 |
| 0.175 | 7.1547 | 0.7717 | 0.0075 | 0.1079 | 4.5859 | 0.3733 |
| 0.185 | 7.1451 | 0.7425 | 0.0076 | 0.1039 | 4.6677 | 0.3736 |
| 0.19 | 7.1415 | 0.7327 | 0.0077 | 0.1026 | 4.7322 | 0.3737 |
| 0.2 | 7.1347 | 0.7058 | 0.0078 | 0.0989 | 4.8009 | 0.3739 |
| 0.205 | 7.1305 | 0.696 | 0.0079 | 0.0976 | 4.8547 | 0.374 |
| 0.215 | 7.1243 | 0.6747 | 0.0081 | 0.0947 | 4.9379 | 0.3742 |
| 0.225 | 7.1161 | 0.6562 | 0.0082 | 0.0922 | 5.0289 | 0.3745 |
| 0.235 | 7.1111 | 0.64 | 0.0084 | 0.09 | 5.1245 | 0.3746 |
| 0.245 | 7.1038 | 0.6227 | 0.0085 | 0.0877 | 5.2013 | 0.3748 |
| 0.255 | 7.0961 | 0.6068 | 0.0086 | 0.0855 | 5.2783 | 0.3751 |
| 0.265 | 7.0906 | 0.5936 | 0.0087 | 0.0837 | 5.3683 | 0.3752 |
| 0.275 | 7.0848 | 0.5813 | 0.0089 | 0.0821 | 5.4586 | 0.3754 |
| 0.29 | 7.0754 | 0.5636 | 0.0091 | 0.0797 | 5.5848 | 0.3756 |
| 0.3 | 7.0722 | 0.5536 | 0.0092 | 0.0783 | 5.6758 | 0.3757 |
| 0.315 | 7.065 | 0.5386 | 0.0094 | 0.0762 | 5.8017 | 0.3759 |
| 0.325 | 7.0594 | 0.528 | 0.0095 | 0.0748 | 5.8705 | 0.3761 |
| 0.34 | 7.0532 | 0.5168 | 0.0098 | 0.0733 | 6.0135 | 0.3763 |
| 0.355 | 7.0446 | 0.5028 | 0.0099 | 0.0714 | 6.1133 | 0.3765 |
| 0.37 | 7.0425 | 0.4936 | 0.0102 | 0.0701 | 6.2562 | 0.3766 |
| 0.385 | 7.037 | 0.4841 | 0.0104 | 0.0688 | 6.3863 | 0.3767 |
| 0.405 | 7.031 | 0.4716 | 0.0106 | 0.0671 | 6.5476 | 0.3769 |
| 0.42 | 7.0267 | 0.4639 | 0.0108 | 0.066 | 6.6823 | 0.377 |
| 0.44 | 7.0198 | 0.454 | 0.0111 | 0.0647 | 6.855 | 0.3772 |
| 0.455 | 7.015 | 0.446 | 0.0113 | 0.0636 | 6.9661 | 0.3774 |
| 0.475 | 7.0094 | 0.4373 | 0.0115 | 0.0624 | 7.1326 | 0.3775 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.495 | 7.0022 | 0.4286 | 0.0118 | 0.0612 | 7.2888 | 0.3777 |
| 0.52 | 6.9925 | 0.4172 | 0.0121 | 0.0597 | 7.4585 | 0.378 |
| 0.54 | 6.9819 | 0.4064 | 0.0122 | 0.0582 | 7.5511 | 0.3783 |
| 0.565 | 6.9634 | 0.3767 | 0.0118 | 0.0541 | 7.3327 | 0.3788 |
| 0.585 | 7.0064 | 0.314 | 0.0102 | 0.0448 | 6.3115 | 0.3777 |
| 0.61 | 7.039 | 0.3756 | 0.0127 | 0.0534 | 7.8517 | 0.3768 |
| 0.64 | 7.023 | 0.3887 | 0.0138 | 0.0553 | 8.5343 | 0.3772 |
| 0.665 | 7.015 | 0.3892 | 0.0144 | 0.0555 | 8.8848 | 0.3774 |
| 0.695 | 7.0088 | 0.3884 | 0.015 | 0.0554 | 9.2711 | 0.3776 |
| 0.725 | 7.0059 | 0.3881 | 0.0156 | 0.0554 | 9.6655 | 0.3777 |
| 0.755 | 6.9991 | 0.3843 | 0.0161 | 0.0549 | 9.9729 | 0.3778 |
| 0.785 | 6.9974 | 0.3856 | 0.0168 | 0.0551 | 10.4046 | 0.3779 |
| 0.82 | 6.9942 | 0.3861 | 0.0176 | 0.0552 | 10.8854 | 0.378 |
| 0.855 | 6.9916 | 0.3861 | 0.0184 | 0.0552 | 11.3516 | 0.378 |
| 0.895 | 6.988 | 0.388 | 0.0193 | 0.0555 | 11.9438 | 0.3781 |
| 0.93 | 6.9853 | 0.3896 | 0.0201 | 0.0558 | 12.4652 | 0.3782 |
| 0.97 | 6.982 | 0.3916 | 0.0211 | 0.0561 | 13.0702 | 0.3783 |
| 1.015 | 6.9795 | 0.3954 | 0.0223 | 0.0567 | 13.8118 | 0.3784 |
| 1.055 | 6.9787 | 0.3997 | 0.0234 | 0.0573 | 14.5125 | 0.3784 |
| 1.1 | 6.9789 | 0.4094 | 0.025 | 0.0587 | 15.4992 | 0.3784 |
| 1.15 | 6.9681 | 0.4213 | 0.0269 | 0.0605 | 16.6882 | 0.3787 |
| 1.195 | 6.9538 | 0.4223 | 0.0281 | 0.0607 | 17.4005 | 0.379 |
| 1.25 | 6.9469 | 0.4228 | 0.0294 | 0.0609 | 18.2318 | 0.3792 |
| 1.3 | 6.943 | 0.4254 | 0.0308 | 0.0613 | 19.082 | 0.3793 |
| 1.36 | 6.9381 | 0.4317 | 0.0326 | 0.0622 | 20.2629 | 0.3795 |
| 1.415 | 6.9321 | 0.4376 | 0.0344 | 0.0631 | 21.3829 | 0.3796 |
| 1.475 | 6.9239 | 0.4436 | 0.0364 | 0.0641 | 22.607 | 0.3798 |
| 1.54 | 6.9151 | 0.448 | 0.0384 | 0.0648 | 23.8502 | 0.3801 |
| 1.605 | 6.9071 | 0.4509 | 0.0402 | 0.0653 | 25.0326 | 0.3803 |
| 1.675 | 6.8982 | 0.4524 | 0.0421 | 0.0656 | 26.2295 | 0.3805 |
| 1.745 | 6.8927 | 0.4437 | 0.0431 | 0.0644 | 26.8104 | 0.3807 |
| 1.82 | 6.912 | 0.4504 | 0.0456 | 0.0652 | 28.3468 | 0.3802 |
| 1.9 | 6.9109 | 0.4711 | 0.0498 | 0.0682 | 30.9504 | 0.3802 |
| 1.98 | 6.9034 | 0.4863 | 0.0535 | 0.0704 | 33.3155 | 0.3804 |
| 2.065 | 6.894 | 0.4977 | 0.0571 | 0.0722 | 35.5802 | 0.3806 |
| 2.155 | 6.8879 | 0.5027 | 0.0602 | 0.073 | 37.5223 | 0.3808 |
| 2.25 | 6.9001 | 0.5099 | 0.0638 | 0.0739 | 39.7031 | 0.3804 |
| 2.345 | 6.9108 | 0.5672 | 0.074 | 0.0821 | 45.9797 | 0.3801 |
| 2.445 | 6.8526 | 0.5866 | 0.0797 | 0.0856 | 49.7878 | 0.3817 |
| 2.55 | 6.8396 | 0.5763 | 0.0817 | 0.0843 | 51.0664 | 0.382 |
| 2.66 | 6.8386 | 0.583 | 0.0862 | 0.0852 | 53.8886 | 0.3821 |
| 2.775 | 6.8346 | 0.5961 | 0.092 | 0.0872 | 57.502 | 0.3821 |
| 2.89 | 6.8355 | 0.6088 | 0.0978 | 0.0891 | 61.1509 | 0.3821 |
| 3.015 | 6.8272 | 0.6376 | 0.1069 | 0.0934 | 66.8466 | 0.3823 |
| 3.145 | 6.8137 | 0.6514 | 0.1139 | 0.0956 | 71.3087 | 0.3827 |
| 3.28 | 6.8102 | 0.6669 | 0.1216 | 0.0979 | 76.1539 | 0.3827 |
| 3.42 | 6.8079 | 0.6895 | 0.1311 | 0.1013 | 82.1015 | 0.3828 |
| 3.57 | 6.7972 | 0.7214 | 0.1432 | 0.1061 | 89.7252 | 0.383 |
| 3.72 | 6.7768 | 0.7396 | 0.153 | 0.1091 | 95.9861 | 0.3836 |
| 3.88 | 6.7662 | 0.7545 | 0.1628 | 0.1115 | 102.2131 | 0.3838 |
| 4.045 | 6.7582 | 0.7762 | 0.1746 | 0.1149 | 109.6815 | 0.384 |


A.P. HILL, TOP 3 , File: 15JL61724
20 deg C, Mv = 17.4%, 1.480 g/cc (dry)
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz
Real
Imaginary


A.P. HILL, TOP 3 , File: 15JL61724
20 deg C, Mv = 17.4%, 1.480 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
100
10
1
0.1
0.01
10
1
0.1
0.01
0.001
0.01
0.1
1
10

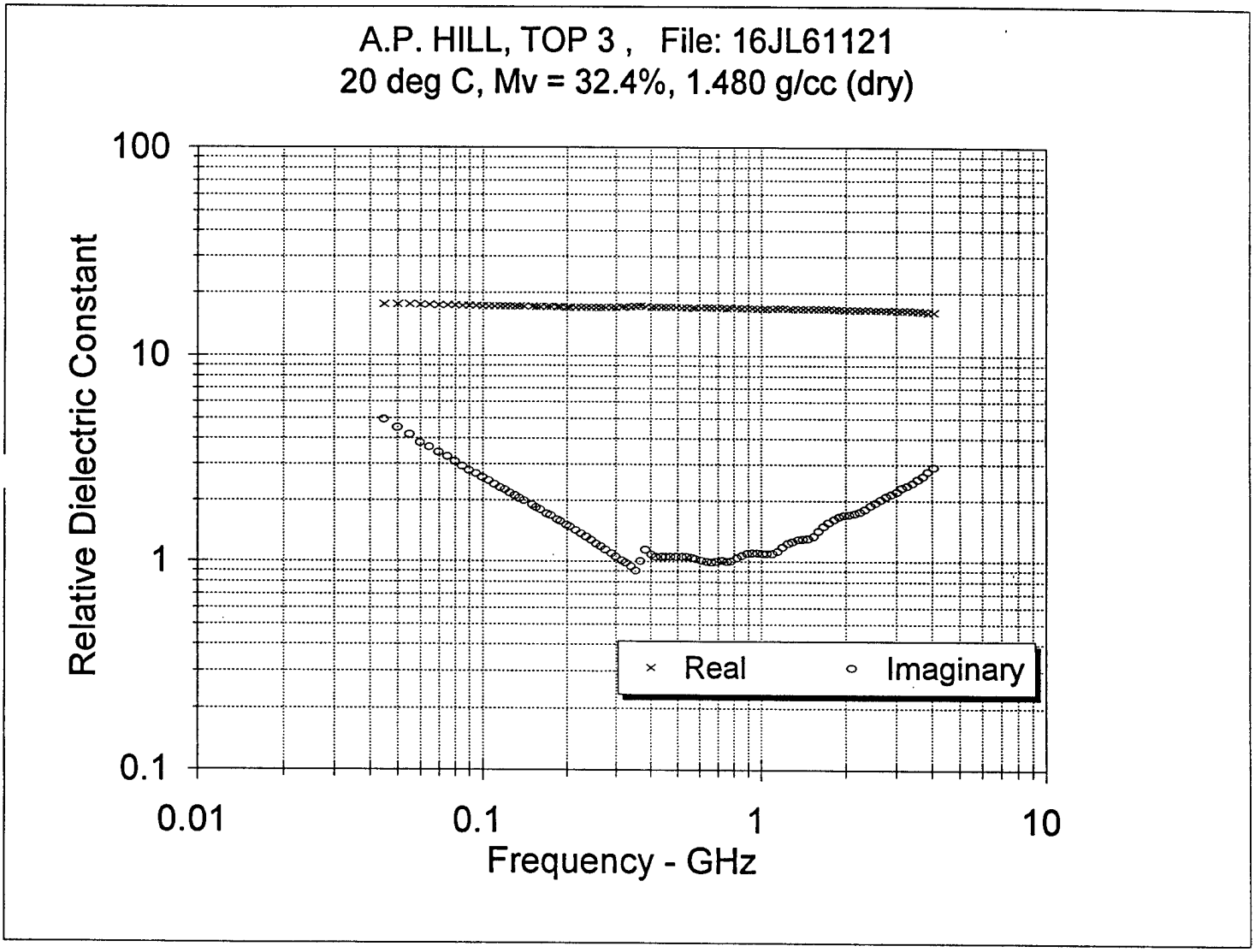

A.P. HILL, TOP 3 , File: 15JL61724
20 deg C, Mv = 17.4%, 1.480 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
1000
100
10
1
0.01
0.1
1
10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

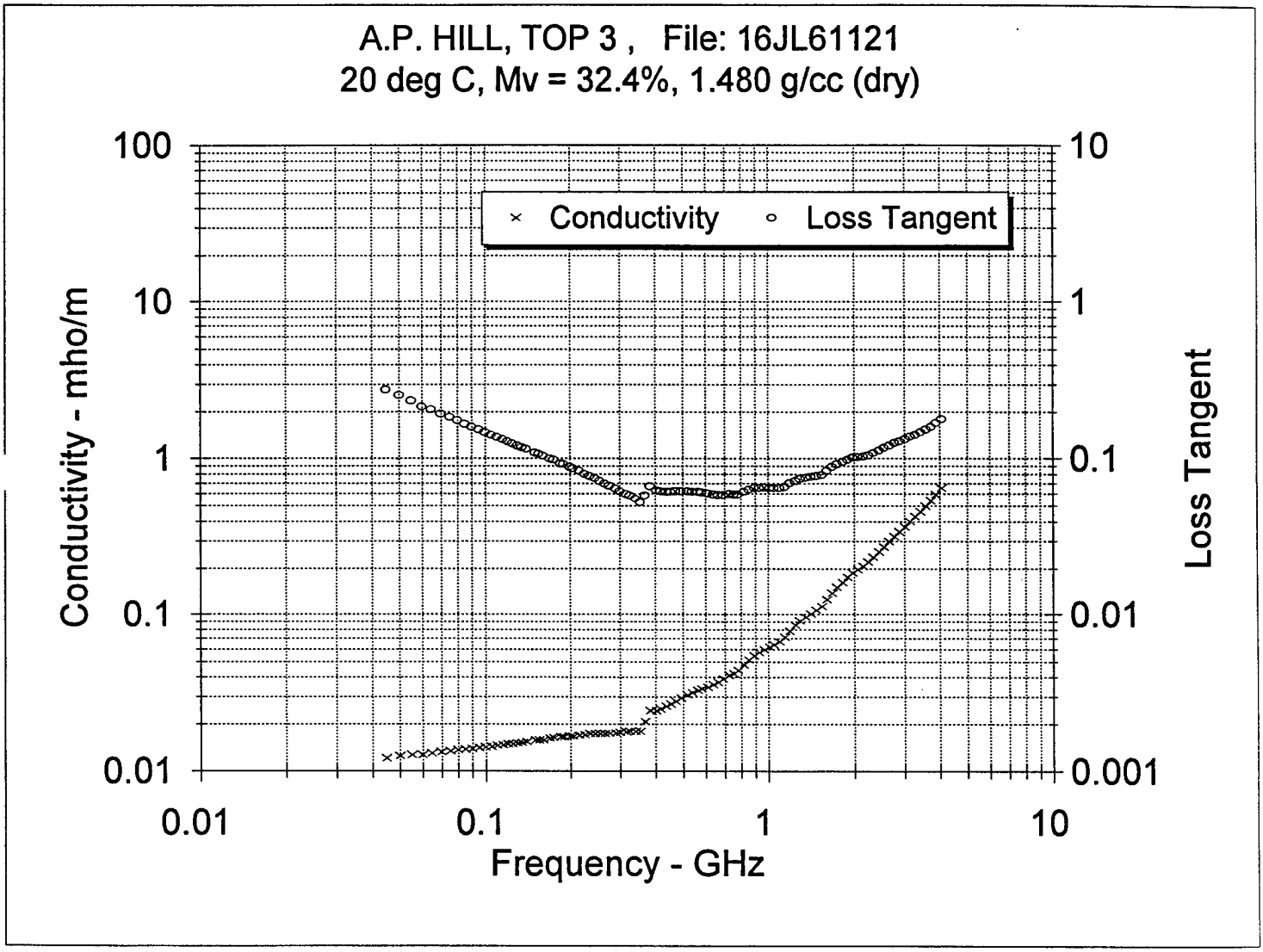
16JL61121
A.P. HILL, TOP 3
9.7
2
32.4
20
1.48

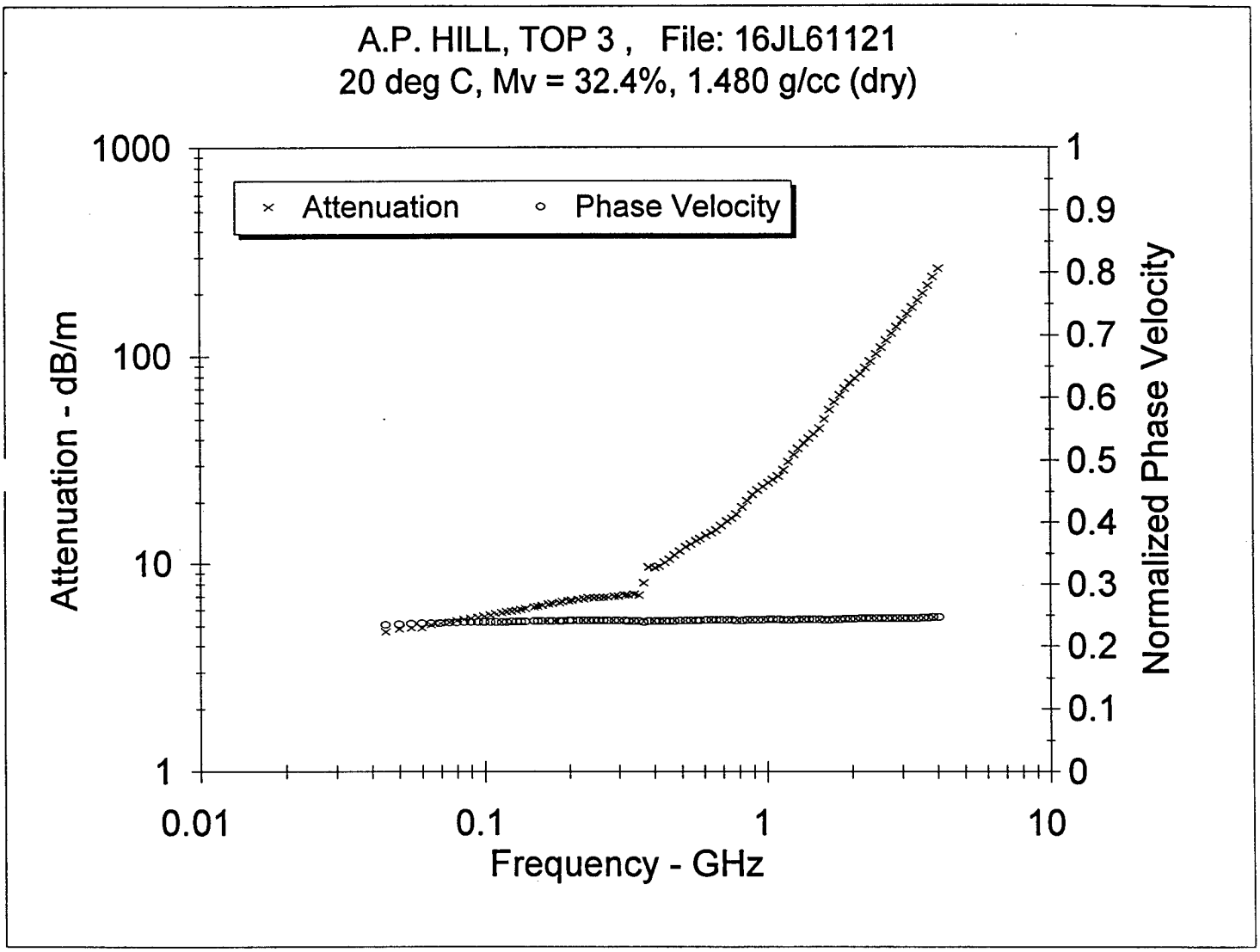
A.P. HILL, TOP 3 , File: 16JL61121
20 deg C, Mv = 32.4%, 1.480 g/cc (dry)

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.045 | 17.6445 | 4.8927 | 0.0122 | 0.2773 | 4.7232 | 0.2359 |
| 0.05 | 17.6005 | 4.5016 | 0.0125 | 0.2558 | 4.8412 | 0.2365 |
| 0.055 | 17.5561 | 4.1513 | 0.0127 | 0.2365 | 4.9227 | 0.237 |
| 0.06 | 17.5112 | 3.7916 | 0.0127 | 0.2165 | 4.9166 | 0.2376 |
| 0.065 | 17.4738 | 3.6187 | 0.0131 | 0.2071 | 5.0912 | 0.238 |
| 0.07 | 17.4501 | 3.4037 | 0.0132 | 0.1951 | 5.1636 | 0.2383 |
| 0.075 | 17.4354 | 3.2313 | 0.0135 | 0.1853 | 5.2569 | 0.2385 |
| 0.08 | 17.3945 | 3.0737 | 0.0137 | 0.1767 | 5.3421 | 0.2388 |
| 0.085 | 17.3572 | 2.9168 | 0.0138 | 0.168 | 5.3941 | 0.2392 |
| 0.09 | 17.331 | 2.7868 | 0.0139 | 0.1608 | 5.4626 | 0.2394 |
| 0.095 | 17.3132 | 2.6758 | 0.0141 | 0.1546 | 5.5405 | 0.2396 |
| 0.1 | 17.2805 | 2.5664 | 0.0143 | 0.1485 | 5.6003 | 0.2399 |
| 0.105 | 17.2512 | 2.4672 | 0.0144 | 0.143 | 5.6587 | 0.2402 |
| 0.11 | 17.2448 | 2.3865 | 0.0146 | 0.1384 | 5.7363 | 0.2402 |
| 0.115 | 17.2166 | 2.3019 | 0.0147 | 0.1337 | 5.79 | 0.2405 |
| 0.12 | 17.2013 | 2.2332 | 0.0149 | 0.1298 | 5.865 | 0.2406 |
| 0.125 | 17.1788 | 2.1584 | 0.015 | 0.1256 | 5.9092 | 0.2408 |
| 0.13 | 17.1581 | 2.0932 | 0.0151 | 0.122 | 5.9642 | 0.241 |
| 0.135 | 17.1454 | 2.0315 | 0.0152 | 0.1185 | 6.0138 | 0.2411 |
| 0.14 | 17.1293 | 1.9821 | 0.0154 | 0.1157 | 6.0884 | 0.2412 |
| 0.15 | 17.1053 | 1.8816 | 0.0157 | 0.11 | 6.198 | 0.2414 |
| 0.155 | 17.0923 | 1.8362 | 0.0158 | 0.1074 | 6.2527 | 0.2415 |
| 0.16 | 17.0757 | 1.7921 | 0.0159 | 0.1049 | 6.3028 | 0.2417 |
| 0.17 | 17.0612 | 1.712 | 0.0162 | 0.1003 | 6.4008 | 0.2418 |
| 0.175 | 17.0427 | 1.6752 | 0.0163 | 0.0983 | 6.4515 | 0.2419 |
| 0.185 | 17.026 | 1.5993 | 0.0165 | 0.0939 | 6.515 | 0.2421 |
| 0.19 | 17.0197 | 1.57 | 0.0166 | 0.0922 | 6.57 | 0.2421 |
| 0.2 | 17.0065 | 1.5086 | 0.0168 | 0.0887 | 6.6485 | 0.2423 |
| 0.205 | 16.9991 | 1.4782 | 0.0168 | 0.087 | 6.6787 | 0.2423 |
| 0.215 | 16.9907 | 1.421 | 0.017 | 0.0836 | 6.7357 | 0.2424 |
| 0.225 | 16.9846 | 1.3683 | 0.0171 | 0.0806 | 6.7895 | 0.2424 |
| 0.235 | 16.9824 | 1.3209 | 0.0173 | 0.0778 | 6.8462 | 0.2425 |
| 0.245 | 16.9789 | 1.2695 | 0.0173 | 0.0748 | 6.8608 | 0.2425 |
| 0.255 | 16.977 | 1.2213 | 0.0173 | 0.0719 | 6.8706 | 0.2425 |
| 0.265 | 16.9867 | 1.1821 | 0.0174 | 0.0696 | 6.9091 | 0.2425 |
| 0.275 | 16.989 | 1.1424 | 0.0175 | 0.0672 | 6.929 | 0.2425 |
| 0.29 | 17.0028 | 1.0912 | 0.0176 | 0.0642 | 6.977 | 0.2424 |
| 0.3 | 17.0129 | 1.059 | 0.0177 | 0.0622 | 7.0024 | 0.2423 |
| 0.315 | 17.0291 | 1.0174 | 0.0178 | 0.0597 | 7.0609 | 0.2422 |
| 0.325 | 17.0464 | 0.9898 | 0.0179 | 0.0581 | 7.0839 | 0.2421 |
| 0.34 | 17.0756 | 0.9521 | 0.018 | 0.0558 | 7.1226 | 0.2419 |
| 0.355 | 17.1351 | 0.908 | 0.0179 | 0.053 | 7.0806 | 0.2415 |
| 0.37 | 17.3058 | 1.0037 | 0.0207 | 0.058 | 8.1165 | 0.2403 |
| 0.385 | 17.1483 | 1.1402 | 0.0244 | 0.0665 | 9.6372 | 0.2414 |
| 0.405 | 17.0781 | 1.0796 | 0.0243 | 0.0632 | 9.6193 | 0.2419 |
| 0.42 | 17.0712 | 1.0617 | 0.0248 | 0.0622 | 9.8123 | 0.2419 |
| 0.44 | 17.0617 | 1.0572 | 0.0259 | 0.062 | 10.2382 | 0.242 |
| 0.455 | 17.0543 | 1.0575 | 0.0268 | 0.062 | 10.5923 | 0.242 |
| 0.475 | 17.0404 | 1.0602 | 0.028 | 0.0622 | 11.0908 | 0.2421 |

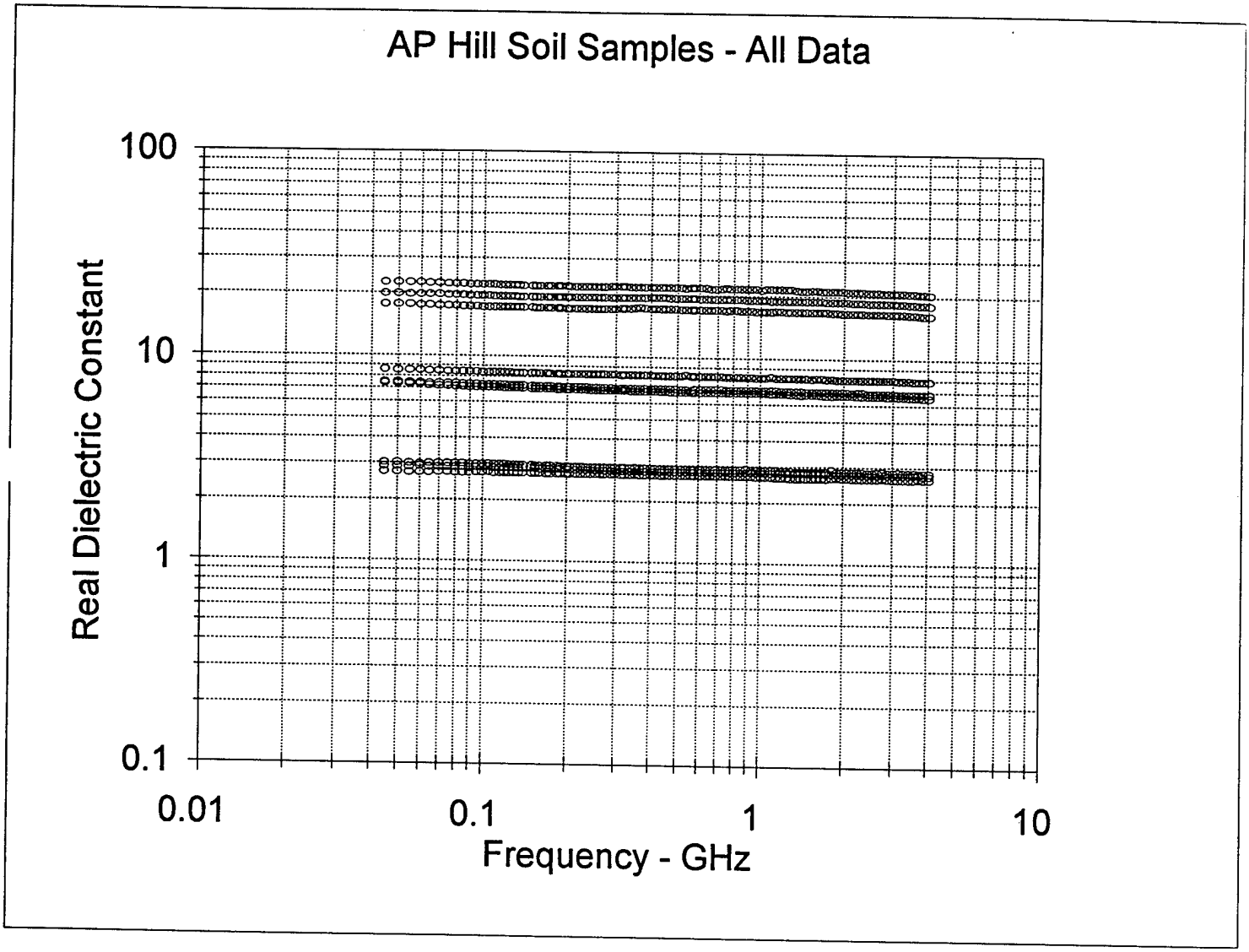
| | | | | | | |
|---|---|---|---|---|---|---|
| 0.495 | 17.0218 | 1.0622 | 0.0292 | 0.0624 | 11.5863 | 0.2423 |
| 0.52 | 16.9992 | 1.0584 | 0.0306 | 0.0623 | 12.1362 | 0.2424 |
| 0.54 | 16.9835 | 1.0523 | 0.0316 | 0.062 | 12.5362 | 0.2425 |
| 0.565 | 16.9628 | 1.0407 | 0.0327 | 0.0614 | 12.9796 | 0.2427 |
| 0.585 | 16.9506 | 1.0302 | 0.0335 | 0.0608 | 13.3082 | 0.2428 |
| 0.61 | 16.9382 | 1.0174 | 0.0345 | 0.0601 | 13.7094 | 0.2429 |
| 0.64 | 16.9323 | 1.0034 | 0.0357 | 0.0593 | 14.1886 | 0.2429 |
| 0.665 | 16.9322 | 0.9971 | 0.0369 | 0.0589 | 14.6502 | 0.2429 |
| 0.695 | 16.9348 | 0.9994 | 0.0386 | 0.059 | 15.3451 | 0.2429 |
| 0.725 | 16.9297 | 1.0124 | 0.0408 | 0.0598 | 16.2187 | 0.2429 |
| 0.755 | 16.9168 | 0.999 | 0.0419 | 0.0591 | 16.6723 | 0.243 |
| 0.785 | 16.9483 | 1.0072 | 0.044 | 0.0594 | 17.4618 | 0.2428 |
| 0.82 | 16.9454 | 1.0448 | 0.0476 | 0.0617 | 18.9213 | 0.2428 |
| 0.855 | 16.9236 | 1.0733 | 0.051 | 0.0634 | 20.2797 | 0.243 |
| 0.895 | 16.8906 | 1.0943 | 0.0545 | 0.0648 | 21.6654 | 0.2432 |
| 0.93 | 16.8637 | 1.1028 | 0.057 | 0.0654 | 22.7054 | 0.2434 |
| 0.97 | 16.8369 | 1.1038 | 0.0595 | 0.0656 | 23.7206 | 0.2436 |
| 1.015 | 16.8207 | 1.0998 | 0.0621 | 0.0654 | 24.7447 | 0.2437 |
| 1.055 | 16.8171 | 1.096 | 0.0643 | 0.0652 | 25.6333 | 0.2437 |
| 1.1 | 16.8216 | 1.0924 | 0.0668 | 0.0649 | 26.6359 | 0.2437 |
| 1.15 | 16.863 | 1.1204 | 0.0716 | 0.0664 | 28.5244 | 0.2434 |
| 1.195 | 16.8559 | 1.1771 | 0.0782 | 0.0698 | 31.1442 | 0.2434 |
| 1.25 | 16.833 | 1.2241 | 0.0851 | 0.0727 | 33.901 | 0.2436 |
| 1.3 | 16.8081 | 1.2532 | 0.0906 | 0.0746 | 36.1189 | 0.2437 |
| 1.36 | 16.7817 | 1.2752 | 0.0964 | 0.076 | 38.4798 | 0.2439 |
| 1.415 | 16.7686 | 1.2896 | 0.1015 | 0.0769 | 40.502 | 0.244 |
| 1.475 | 16.7683 | 1.2979 | 0.1065 | 0.0774 | 42.4913 | 0.244 |
| 1.54 | 16.8161 | 1.3238 | 0.1134 | 0.0787 | 45.1855 | 0.2437 |
| 1.605 | 16.8308 | 1.4069 | 0.1256 | 0.0836 | 50.0223 | 0.2435 |
| 1.675 | 16.812 | 1.4885 | 0.1386 | 0.0885 | 55.2567 | 0.2436 |
| 1.745 | 16.7777 | 1.5526 | 0.1507 | 0.0925 | 60.1002 | 0.2439 |
| 1.82 | 16.7382 | 1.6039 | 0.1623 | 0.0958 | 64.8267 | 0.2441 |
| 1.9 | 16.698 | 1.6567 | 0.175 | 0.0992 | 69.9792 | 0.2444 |
| 1.98 | 16.6424 | 1.6898 | 0.186 | 0.1015 | 74.504 | 0.2448 |
| 2.065 | 16.6019 | 1.7014 | 0.1954 | 0.1025 | 78.3281 | 0.2451 |
| 2.155 | 16.5833 | 1.7154 | 0.2056 | 0.1034 | 82.4597 | 0.2452 |
| 2.25 | 16.5823 | 1.7439 | 0.2182 | 0.1052 | 87.5229 | 0.2452 |
| 2.345 | 16.5851 | 1.8044 | 0.2353 | 0.1088 | 94.3677 | 0.2452 |
| 2.445 | 16.5615 | 1.8748 | 0.2549 | 0.1132 | 102.2903 | 0.2453 |
| 2.55 | 16.5372 | 1.9402 | 0.2751 | 0.1173 | 110.4747 | 0.2455 |
| 2.66 | 16.5175 | 2.0067 | 0.2968 | 0.1215 | 119.2447 | 0.2456 |
| 2.775 | 16.5002 | 2.0773 | 0.3205 | 0.1259 | 128.8276 | 0.2457 |
| 2.89 | 16.4856 | 2.142 | 0.3442 | 0.1299 | 138.3885 | 0.2458 |
| 3.015 | 16.4754 | 2.2088 | 0.3703 | 0.1341 | 148.904 | 0.2458 |
| 3.145 | 16.4571 | 2.2799 | 0.3987 | 0.1385 | 160.3878 | 0.2459 |
| 3.28 | 16.4259 | 2.3512 | 0.4288 | 0.1431 | 172.6369 | 0.2461 |
| 3.42 | 16.3819 | 2.4243 | 0.461 | 0.148 | 185.8244 | 0.2464 |
| 3.57 | 16.326 | 2.5183 | 0.4999 | 0.1543 | 201.7904 | 0.2468 |
| 3.72 | 16.2681 | 2.6223 | 0.5424 | 0.1612 | 219.2828 | 0.2471 |
| 3.88 | 16.2194 | 2.754 | 0.5942 | 0.1698 | 240.4744 | 0.2474 |
| 4.045 | 16.184 | 2.9014 | 0.6526 | 0.1793 | 264.3022 | 0.2476 |

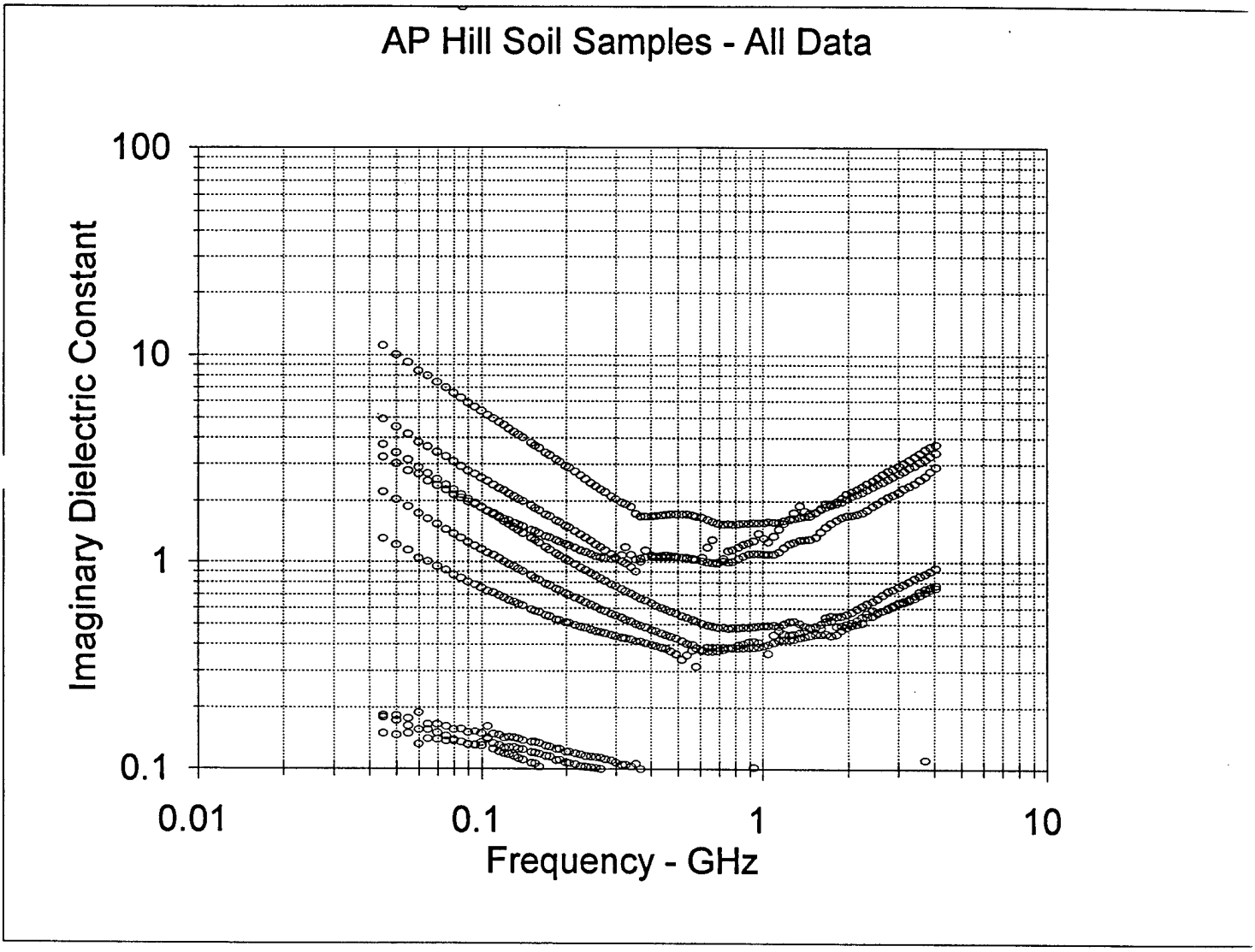

A.P. HILL, TOP 3 , File: 16JL61121
20 deg C, Mv = 32.4%, 1.480 g/cc (dry)
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz
Real
Imaginary

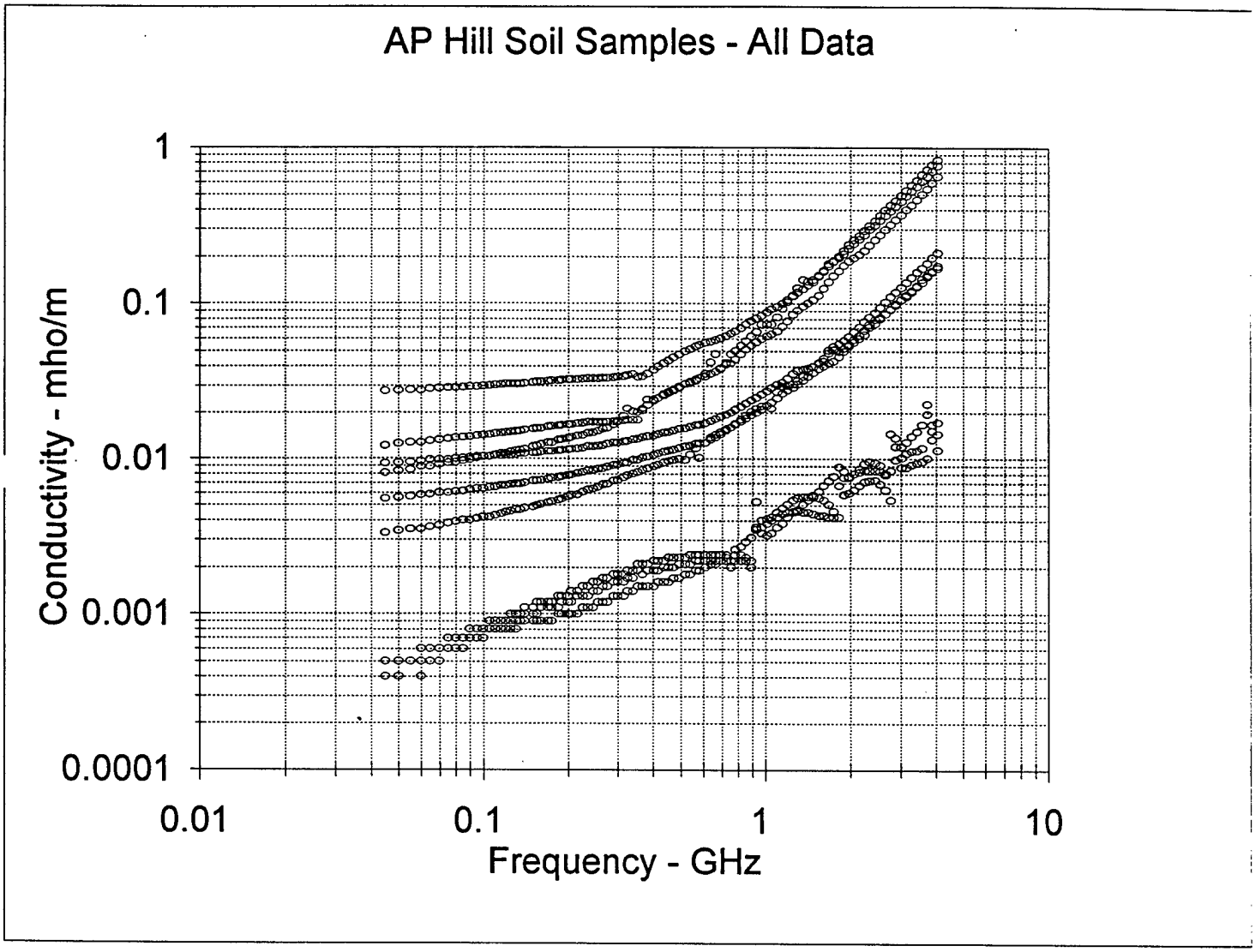

A.P. HILL, TOP 3 , File: 16JL61121
20 deg C, Mv = 32.4%, 1.480 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
100
10
1
0.1
0.01
10
1
0.1
0.01
0.001
0.01
0.1
1
10

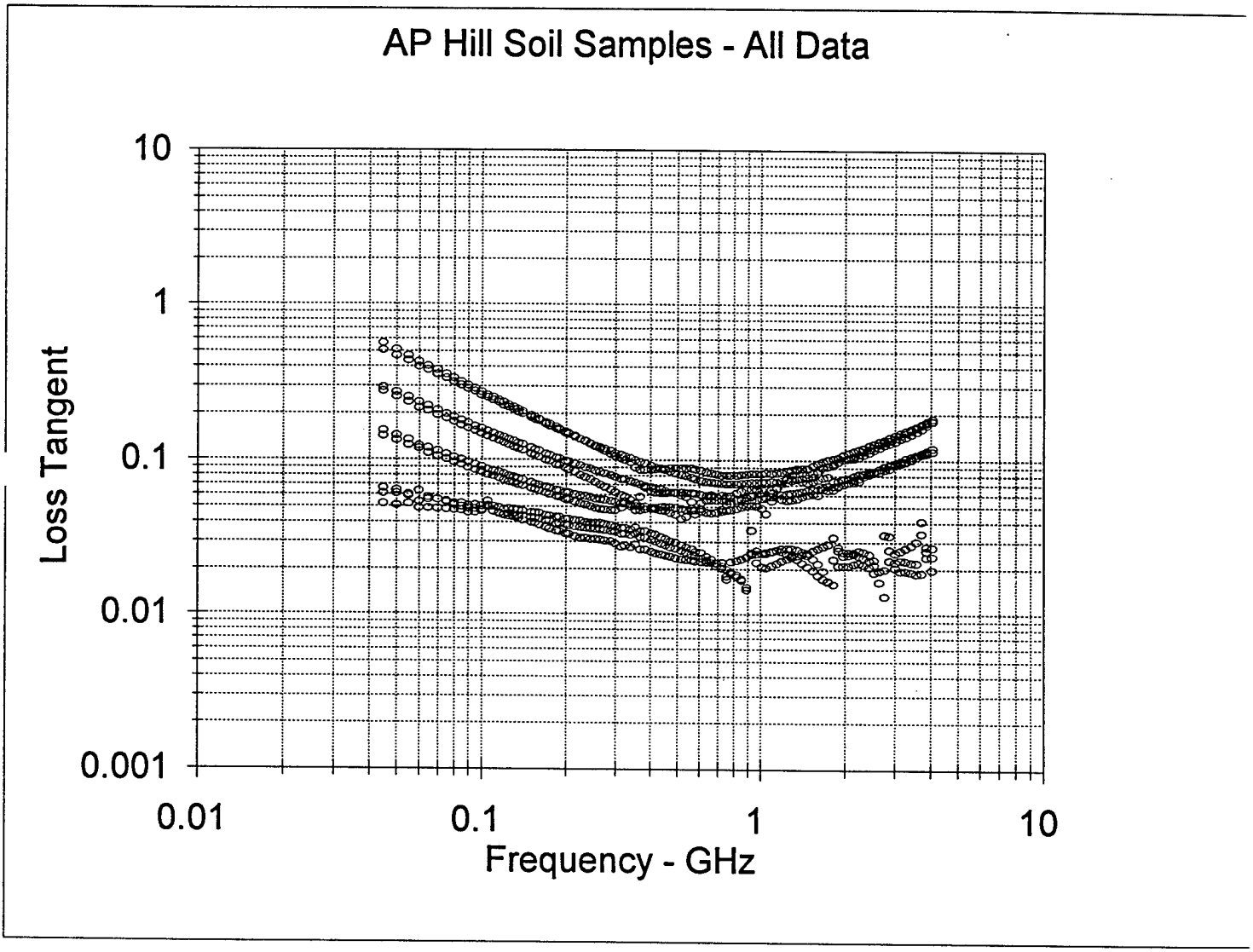

A.P. HILL, TOP 3 , File: 16JL61121
20 deg C, Mv = 32.4%, 1.480 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
1000
100
10
1
0.01
0.1
1
10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

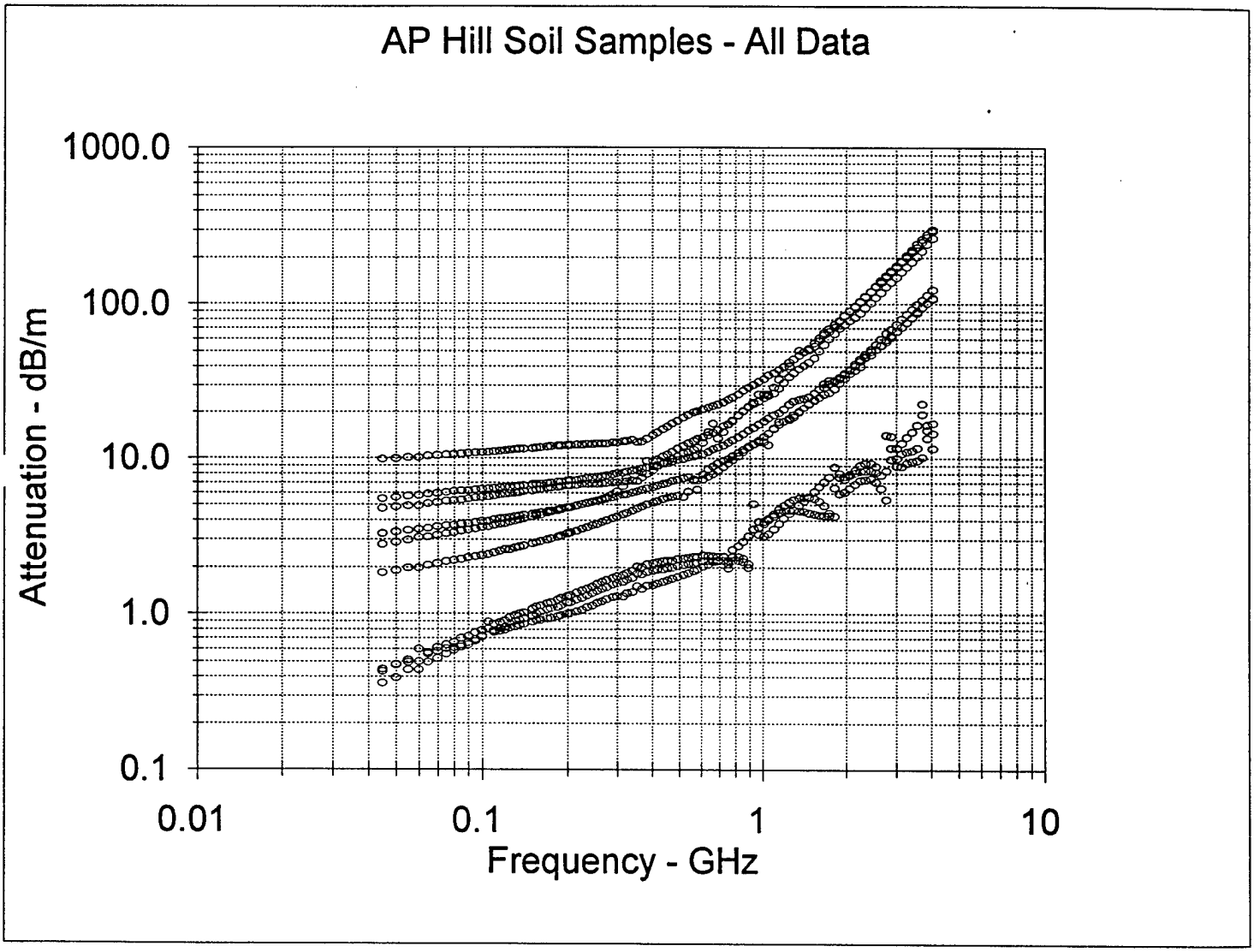
# Fort A.P. Hill
# Collective Sample Results

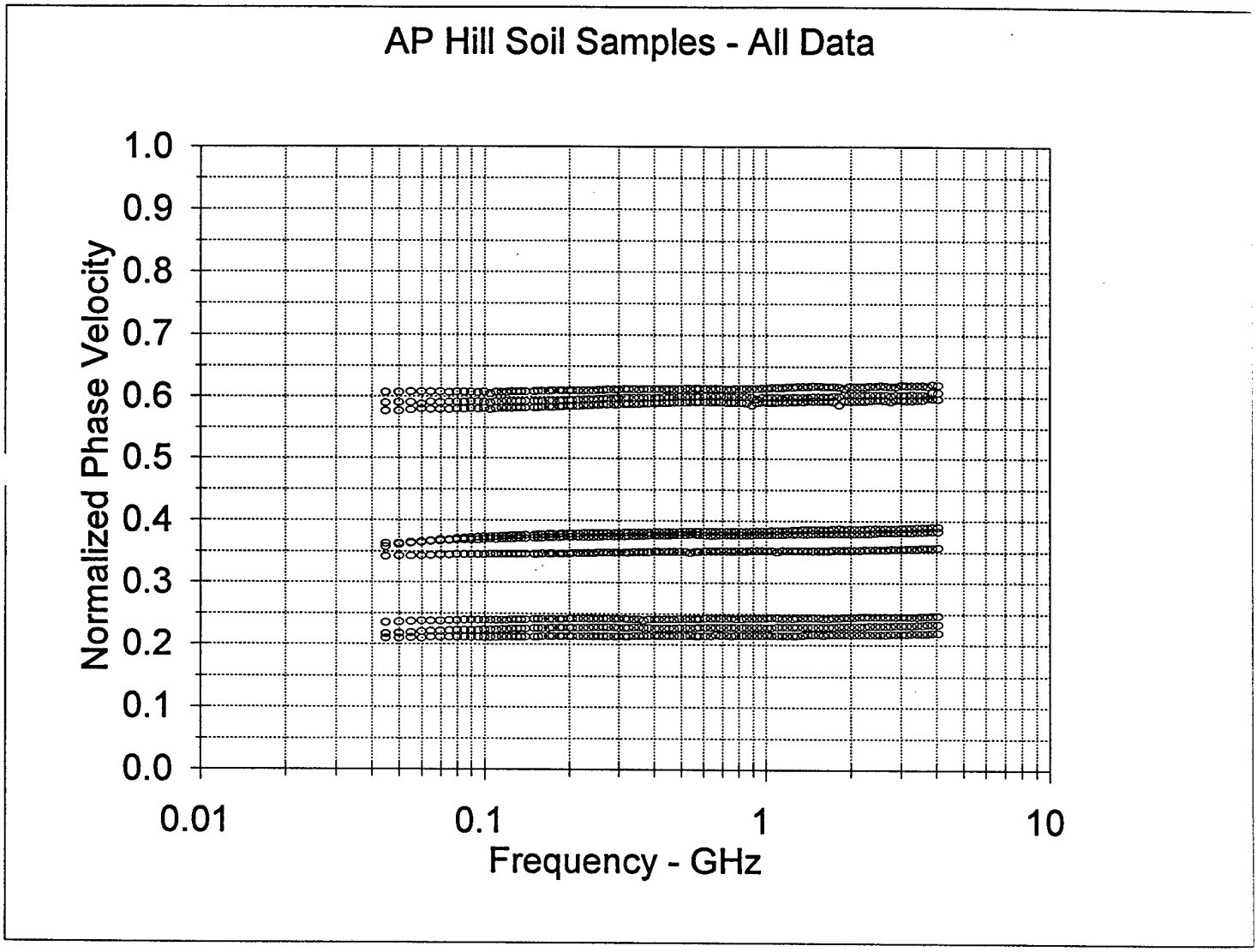

AP Hill Soil Samples - All Data
100
10
1
0.1
Real Dielectric Constant
0.01
0.1
1
10
Frequency - GHz


AP Hill Soil Samples - All Data
Imaginary Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz


AP Hill Soil Samples - All Data
Conductivity - mho/m
1
0.1
0.01
0.001
0.0001
0.01
0.1
1
10
Frequency - GHz

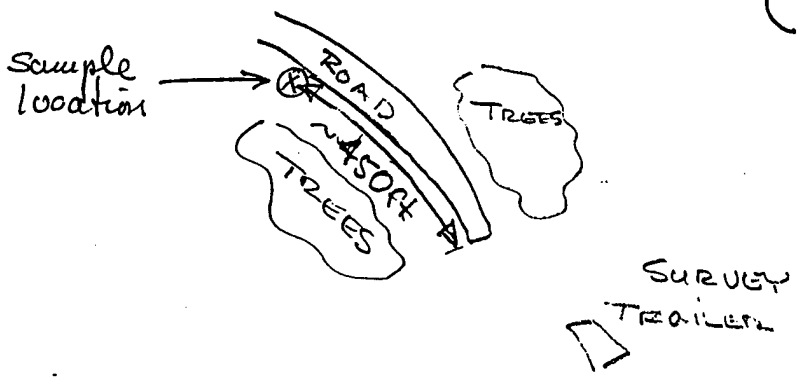

AP Hill Soil Samples - All Data
Loss Tangent
10
1
0.1
0.01
0.001
0.01
0.1
1
10
Frequency - GHz


AP Hill Soil Samples - All Data
1000.0
100.0
10.0
1.0
0.1
Attenuation - dB/m
0.01
0.1
1
10
Frequency - GHz


AP Hill Soil Samples - All Data
Normalized Phase Velocity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.01
0.1
1
10
Frequency - GHz

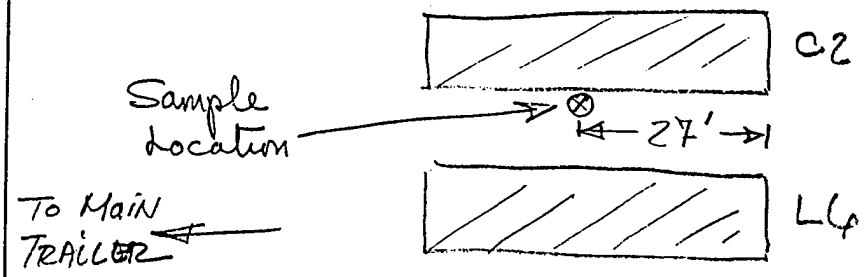
Ft. A.P. Hill Soil Samples
Collected 21 MAR 96

① Sample - OFF Road
Collected in off Road Area (Material collected in top 4")




NOT to Scale

② Sample - top 3"
Collected by hand held Area

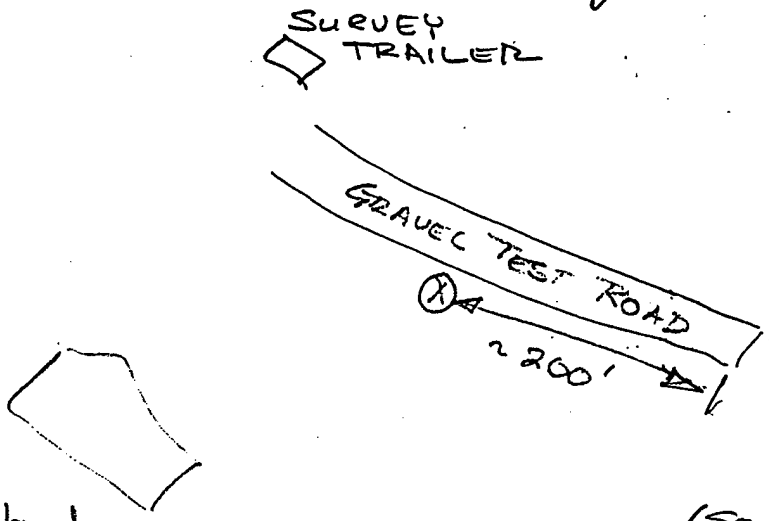



NOT TO SCALE

(Sample collected in top 3")

③ Sample - Dart Road

Sample collected by Vehicle Road




NOT TO SCALE